PB-228 435

WATER QUALITY CONTROL STUDY, ENGLISH RIDGE RESERVOIR, EEL RIVER BASIN, CALIFORNIA

Federal Water Pollution Control Administration
San Francisco, California

August 1969

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EEL RIVER BASIN
CALIFORNIA

ENGLISH RIDGE PROJECT

WATER QUALITY CONTROL STUDY

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U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC SOUTHWEST REGION SAN FRANCISCO, CALIF.
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WATER QUALITY CONTROL STUDY
ENGLISH RIDGE RESERVOIR
EEL RIVER BASIN, CALIFORNIA

ABSTRACT

Construction and operation of the English Ridge Reservoir, as proposed by the U. S. Bureau of Reclamation, together with the naturally available flows from the remaining drainage area, will provide flows in the Eel River downstream from English Ridge Reservoir that will be sufficient to maintain adequate water quality for the fishery and other beneficial uses of the river's waters. Additional storage in English Ridge reservoir for water quality control in the Eel River will not be needed within the next fifty years.

The planned diversion of stored water through Clear Lake will enhance the water quality of Clear Lake, and thereby improve its aesthetic and recreational values. The monetary value of these benefits to Clear Lake is estimated to be in excess of twenty million dollars.

U. S. DEPARTMENT OF THE INTERIOR

FEDERAL WATER POLLUTION CONTROL ADMINISTRATION

PACIFIC SOUTHWEST REGION

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I. INTRODUCTION

BACKGROUND

Proposals for development of the water resources of the Eel River in northern California include the U. S. Bureau of Reclamation's English Ridge Project on the upper mainstem of the Eel River and the U. S. Army Corps of Engineer's Dos Rios Project on the Middle Fork of the Eel River. Both of these projects are currently the subject of feasibility studies. Neither project has as yet been authorized by Congress for construction. Both involve trans-mountain diversion of water from the Eel River to the Sacramento River Basin for use in water deficient areas of northern, central, and southern California.

It is possible to export water from these Eel River Projects to the Sacramento River Basin by separate routes or by a single joint route. An eastern route has been proposed to convey water from Dos Rios Reservoir through Grindstone Tunnel and Stony Creek to the Sacramento River. A southern route has been proposed to convey diversions from the English Ridge Reservoir through Garrett Tunnel, Clear Lake, and Putah-Cache Creeks to the Sacramento River. A joint southerly route is also possible whereby water would be transferred from Dos Rios Reservoir to the English Ridge Reservoir via the seven mile long Elk Creek Tunnel. From this latter reservoir, water from both projects would be conveyed to the Sacramento River Basin by the southern route described above.

Thus, the English Ridge Project is related to the route selected for diversion of water from the proposed Dos Rios Project. If the easterly route is selected, water from Dos Rios Reservoir would not enter English Ridge Reservoir and the English Ridge Project would be proposed as an independent project. If the southerly route is selected for diversion of Dos Rios water, the two projects would be integrated operationally and financially. The English Ridge Project considered in this report is that which would operate independently of the proposed Dos Rios Project.

PURPOSE AND SCOPE

The purpose of this report is to describe (1) the need for and value of reservoir storage for streamflow regulation for water quality control, and (2) the potential impact of the project on water quality. Since the English Ridge Project involves trans-basin diversions of water, the study area includes the Eel River Basin and the area traversed by the trans-basin export route. The purposes of the English Ridge Project include irrigation, municipal and industrial water supply, recreation, fish and wildlife, flood control, as well as trans-basin exportation of water to the Sacramento River Basin, thence to water deficient areas in the San Joaquin Valley, and central and southern coastal areas of California.

The time period considered in this study is 1970 to 2020. An interest rate of 4.625% was used for monetary evaluations. The report is based on existing engineering and economic data, limited collection and laboratory analyses of field samples, and information provided by local, state and federal agencies.

AUTHORITY

This report was prepared in accordance with (1) the Federal Water Pollution Control Act, as amended (33 U.S.C. 466 et seq.) and (2) Executive Order 11288, July 2, 1966.

ACKNOWLEDGMENTS

This study was materially aided by the cooperation and assistance of the following:

U.S. Bureau of Reclamation, Region 2
Sacramento, California

U.S. Army, Corps of Engineers, San Francisco District
San Francisco, California

U.S. Bureau of Outdoor Recreation
San Francisco, California

U.S. Geological Survey
Menlo Park, California

U.S. Soil Conservation Service
Berkeley, California

California State Department of Water Resources
Red Bluff, California

Central Valley Regional Water Quality Control Board
Sacramento, California

North Coastal Regional Water Quality Control Board
Santa Rosa, California

Lake County Chamber of Commerce
Lakeport, California

Lake County Mosquito Abatement District
Lakeport, California

Lake County Flood Control and Water Conservation District
Lakeport, California

Dr. Charles R. Goldman
Institute of Ecology
University of California
Davis, California

II. SUMMARY OF FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

FINDINGS

1. The population of the Eel River Basin was 39,850 in 1960 and is expected to reach 126,000 by the year 2020. The economy of the Basin is based primarily upon the timber industry, agriculture, and recreation. It is an area with an abundant water supply which is essentially undeveloped.

2. A major water quality problem in the Eel River is high turbidity caused by excessive suspended sediment during periods of peak runoff.

3. The English Ridge Reservoir will release 126,000 acre-feet of water per year to maintain the existing Eel River fishery. Fish hatchery facilities will also be constructed to mitigate losses of salmon and steelhead due to construction of the project. The California North Coastal Regional Water Quality Control Board requires a minimum dissolved oxygen concentration of 7.0 mg/l throughout the Eel River for protection of these anadromous fishery resources.

4. In addition to such in-basin benefits as flood control and recreation, development of the Eel River will provide surplus water for export to the Sacramento River. An average of 190,000 acre-feet per year will be exported by gravity flow through Garrett Tunnel into the Clear Lake Basin. Approximately 40,000 acre-feet will be utilized to meet irrigation requirements in the Clear Lake area. About 21,000 acre-feet will be diverted from Cache Creek to Putah Creek for irrigation use. An additional quantity of approximately 37,000 acre-feet will be diverted from Cache Creek via canals on the west side of the Sacramento Valley for irrigation use in Solano County. The remaining 92,000 acre-feet will be released to the Sacramento River for the Delta Pool, where it will be subject to local use, export, and release to the San Francisco Bay system for salinity control.

5. The Putah-Cache Creek Basin has a present population of 32,000 and the economy is almost entirely dependent upon recreation and agriculture. The basin has extensive areas of irrigable land which could be converted to irrigated agriculture and would require additional quantities of water. Recreation activity is centered around popular Clear Lake which had a recreational use of 2,500,000 visitor days in 1967 with a potential for much greater development. The lake is presently highly eutrophic. During the summer months aesthetically objectionable algal growths severely detract from its recreational value. Also, boron concentrations in Clear Lake and Cache Creek exceed the recommended limit of 0.5 mg/l for Class 1 irrigation water.

CONCLUSIONS

1. Operation of English Ridge Reservoir, as proposed by the Bureau of Reclamation, together with naturally available flows from the remaining drainage area, will provide adequate flows in the Eel River for fishery maintenance purposes. These flows will also assure sufficient dissolved oxygen concentrations to protect the fishery during the period of study. Additional separable storage in the English Ridge Reservoir for water quality control for other uses of the Eel River will not be needed during the period of study. This conclusion is based on the assumption that projected waste loads from domestic and recreation sources will receive the equivalent of secondary treatment and that flow releases required to support the fishery and other recreational uses of the river will be accomplished as proposed.

2. Although the operation of English Ridge Reservoir, as proposed by the Bureau of Reclamation, together with naturally available flows from the remaining drainage area will provide adequate downstream flow during the study period, nutrient concentrations in the lower Eel River will approach nuisance levels by 2020 if the equivalent of secondary treatment is provided for domestic and recreational waste loads. Advanced waste treatment or collection and disposal of treated wastes by ocean outfall may be necessary at a later date in order to prevent possible degradation of water quality due to excessive growth of aquatic plants.

3. Routing of water from English Ridge Reservoir as well as from other future Eel River projects through Clear Lake provides a unique opportunity to enhance the quality of Clear Lake waters significantly and thereby increasing beneficial uses including the aesthetic enjoyment of the Lake.

4. Export of Eel River water through Clear Lake will significantly reduce the nutrient and boron concentrations in Clear Lake. Water quality benefits from routing Eel River water through Clear Lake increase in proportion to the quantity of water diverted.

5. Existing excessive nutrient concentrations in Clear Lake could be significantly reduced by advanced treatment of tributary domestic wastes or diversion of these waste flows from the lake basin. Advanced waste treatment to remove 80 percent nitrogen and 90 percent phosphorus would provide water quality benefits to recreation in Clear Lake in excess of 15 million dollars, while diversion of all waste waters for disposal outside of the Clear Lake Basin would yield benefits in excess of 24 million dollars.

6. Recreational benefits due to improved water quality associated with routing English Ridge water (190,000 acre-feet per year) through Clear Lake are estimated to have a present worth in escess of 21

million dollars. If English Ridge water and advanced or tertiary treatment are provided concurrently, the improved water quality would result in increased recreation use having a present worth in excess of 30 million dollars, while the routing of English Ridge water combined with diversion of waste waters outside the Clear Lake Basin would have a present worth in excess of 34 million dollars. Estimates of benefits obtained by routing Eel River water through Clear Lake are net of associated costs.

7. The use of Clear Lake and natural creek channels tributary to the Sacramento River as a part of the conveyance system for waters exported from English Ridge Reservoir minimizes the capital expenditures required to construct the project but at the expense of a reduction in the quality of water exported. The lowering of quality is greatest for project water users around Clear Lake and those diverting from Cache or Putah Creeks, but the nature of these uses is such that the impact will be negligible. The change in quality to users diverting from the Sacramento River will be very small and the economic impact also negligible.

8. Diversion of 21,000 acre-feet of water from the Cache Creek Basin to Putah Creek will increase the nutrient load entering Monticello Reservoir. The effect on nutrient concentration, however, is small and considered to be negligible.

RECOMMENDATIONS

1. Multi-level outlet works should be provided at all outlets and diversion tunnel headworks in English Ridge Reservoir to permit selection of the highest quality of water available for export and downstream releases.

2. The water quality benefits resulting from the routing of Eel River water through Clear Lake are believed to represent reasonable estimates based on current information. Project planning should include specific studies to: (a) establish more firmly the source and amount of nutrients presently entering the lake, (b) demonstrate more fully the effects of dilution of lake waters by Eel River waters, (c) appraise more adequately the future potential recreational use of the lake, and (d) appraise more accurately the relationships of algae, water quality, climate and other such factors to the recreational use of Clear Lake. Current studies of these topics now under way should be continued and enlarged to produce more definitive conclusions on methods of enhancing the quality and beneficial uses of the lake.

3. The Bureau of Outdoor Recreation is currently making a more detailed study of the future potential recreational uses of the Lake. When the results of the current studies become available, the recreational benefits attributable to enhancement of water quality should be re-appraised.

III. STUDY AREAS

The areas considered in this study include the Eel River Basin in northwestern California and the trans-basin export route to the Sacramento River. The study area is shown in Figure 1.*

EEL RIVER BASIN

The Eel River Basin includes parts of Humboldt, Mendocino, Trinity, and Lake Counties in northwestern California. The Basin drains approximately 3,600 square miles of the rugged California Coastal Range.

The Basin extends inland approximately 140 miles in a southeasterly direction through mountains which rise to elevations over 7,000 feet. The topography consists of mountain ridges, except for a few inland valleys and the flat coastal plain south of Humboldt Bay. Principal communities within the basin are Fortuna, Scotia, Garberville, and Willits.

The moderate climate of the coastal area is influenced by the moist air mass over and near the Pacific Ocean. The inland area is subject to a wider range of daily and seasonal temperatures. The average annual temperature of the area varies from 51.6°F at Eureka on Humboldt Bay to 58.4°F at Potter Valley, located inland in Mendocino County. Average annual precipitation varies from about 35 inches per year in the coastal area to a reported maximum of 115 inches per year inland. About 86% of the annual precipitation occurs in the period from November 1 to April 30.

PUTAH-CACHE CREEK BASIN

The Putah-Cache Creek Basin includes approximately 1,519 square miles within Colusa, Lake, Mendocino, Napa, Solano, and Yolo Counties. The upper basin area is mountainous, in contrast to the rolling foothills and the sloping plains of the lower basin that extends to the Sacramento River.

The mountainous upper basin is largely within Lake County which is named for Clear Lake. Clear Lake is the largest natural freshwater lake lying entirely within California. The lake has about 100 miles of shoreline ecompassing 68.5 square miles of open water that drains 457 square miles of watershed. Much of the watershed is mountainous, although there are several large valleys that are suitable for cultivation. Clear Lake is a favorite vacation and recreation area for people from the Sacramento and San Francisco Bay areas. Lake County's present population of approximately 21,000 is centered in the communities of Lakeport, Clearlake Highlands, and Upper Lake, which are located on or near the shoreline of Clear Lake.

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*Figure 1 is located at the end of the report.

The Putah Creek portion of the basin includes Lake Berryessa which is formed by Monticello Dam on Putah Creek. The lake, with a storage capacity of 1,600,000 acre-feet and a maximum water surface area of 30 square miles, receives heavy recreational use.

The flatlands of the lower portion of Putah-Cache Creek Basin are suitable for agricultural activity. Communities such as Woodland, Winters, Davis, Capay, and Yolo are local centers of agricultural activities.

The climate is characterized by dry summers with high daytime temperatures and wet winters with moderate temperatures. Approximately 85% of the annual precipitation occurs in the period from October through March. The average annual precipitation varies from 17 inches at Davis to 65 inches in the mountains.

IV. PROJECT DESCRIPTION

ENGLISH RIDGE PROJECT

The English Ridge Dam, as proposed by the Bureau of Reclamation, would be located on the mainstem of the Eel River, approximately 20 river miles upstream from the town of Dos Rios in Mendocino County. The dam would be an earthfill structure with a height of about 553 feet. The reservoir would have a gross capacity of 1,800,000 acre-feet and a surface area of 11,800 acres at the normal water surface elevation of 1,698 feet. The impoundment would extend for about 28 miles to the toe of the existing Pacific Gas and Electric Company's Scott Dam which forms Lake Pillsbury.

This multi-purpose project will provide water for irrigation, municipal and industrial uses, recreation, fish and wildlife mitigation and flood control. Annual releases of 126,000 acre-feet will be made to the Eel River to maintain the existing fishery. Fish hatchery facilities will also be constructed to mitigate losses of salmon and steelhead. An average annual release of 190,000 acre-feet will be exported by gravity flow through the 14.2 mile long Garrett Tunnel into the Clear Lake Basin. Of this 190,000 acre-feet, approximately 40,000 acre-feet will be utilized to meet irrigation requirements in the Clear Lake area. About 21,000 acre-feet will also be diverted from Cache Creek into the upper Putah Creek to meet local irrigation requirements. An additional 37,000 acre-feet will be diverted from Cache Creek for use in Solano County. The remaining water will be released from Clear Lake into Cache Creek, a tributary of the Sacramento River, to combine with Delta surplus flows. This flow will develop a firm annual yield of 120,000 acre-feet, for subsequent diversion and use in water deficient service areas of the Central Valley Project.

In the future, Eel River water initially assigned to the Central Valley could be exchanged for yield from additional northwestern California projects and reallocated to meet demands of the Russian River Basin and north bay areas, when these demands develop beyond the supplies presently available.

OTHER EEL RIVER PROJECTS

Dos Rios Dam, as proposed by the U. S. Army Corps of Engineers, would be located on the Middle Fork of the Eel River 2.5 miles upstream from the town of Dos Rios in Mendocino County. The dam would be a rockfill structure with a height of approximately 700 feet high. The reservoir would have a normal pool surface water elevation of 1,600 feet and provide a storage capacity of 7,600,000 acre-feet. The reservoir would have a total surface area of approximately 41,000 acres and a shoreline of over 200 miles.

Dos Rios Dam and Reservoir would be operated as a multiple-purpose project and include provisions for the preservation of fisheries, flood control, recreation, and export of water to water deficient areas served by the California Water Project. Water from Dos Rios can be exported via an easterly route through Grindstone Tunnel and Black Butte Reservoir or a southerly route through Elk Creek Tunnel, English Ridge Reservoir, Garrett Tunnel, and Clear Lake.

The U. S. Army Corps of Engineers have indicated that the Dos Rios Project operated in conjunction with surplus waters in the Delta Pool would increase the annual export yield from the Delta, by 900,000 acre-feet. 213,000 acre-feet would be released annually to mitigate fishery losses downstream from the Dos Rios Reservoir.

The Corps of Engineers is also studying the Yellow Jacket Project on the mainstem of the Eel River near Fort Seward. This reservoir could annually supply an additional 800,000 to 1,000,000 acre-feet of water for export to the Sacramento River Basin. The water would be pumped from Yellow Jacket Reservoir to Dos Rios Reservoir where it would be diverted from the basin along with the export water from the Dos Rios Project.

The U. S. Bureau of Reclamation is also studying a possible development on the Van Duzen River, a tributary of the Eel River, at the Dinsmore Dam site. This project would be developed to provide approximately 130,000 acre-feet of water per year for export through the Mad River Basin and into the Lower Trinity for export to the Sacramento Valley. Preliminary estimates indicate that releases of approximately 45,000 acre-feet per year would be made to sustain a fishery in the Van Duzen and the Lower Eel.

Development of the South Fork of the Eel River is also being considered by the State of California. Recreation on the South Fork of the Eel and irrigation requirements on the Lower Eel would be the primary purpose of any development on the South Fork.

Water from the Eel River Basin can be regulated in the Central Valley by means of several possible reservoirs. Rancheria Reservoir on Stony Creek and/or Wilson Valley Reservoir on Cache Creek are most prominently mentioned.

V. EEL RIVER BASIN

ECONOMY

The Eel River Basin is presently a relatively undeveloped area and essentially rural in character. Timber resources constitute the primary base of economic activity in the basin. Over 70 percent of the employment in Humboldt County is related to forest resources such as lumber, pulp, plywood, shingles and veneer. Approximately 1,525,000 acres of commercial timber land containing an estimated 38 billion board feet of timber, produce approximately 15 million dollars of forest products annually [1].

Recreation and agriculture are also important to the economy. Major tourist attractions are state and national forests (including redwoods), state parks, fish and game, and the scenic sea coast. Gross expenditures by recreationists are centered in the Eureka Plain, near the mouth of the Eel River. The native grass and pasture land is utilized primarily for grazing dairy cattle. Gross sales from farm products are approximately 10 million dollars annually [2].

There are many small communities which lie within the study area; the largest are Willits, Rio Dell and Fortuna, each of which had a population of slightly more than 3,000 persons in 1960. Ferndale, Garberville and Scotia had 1960 populations in excess of 1,000 persons.

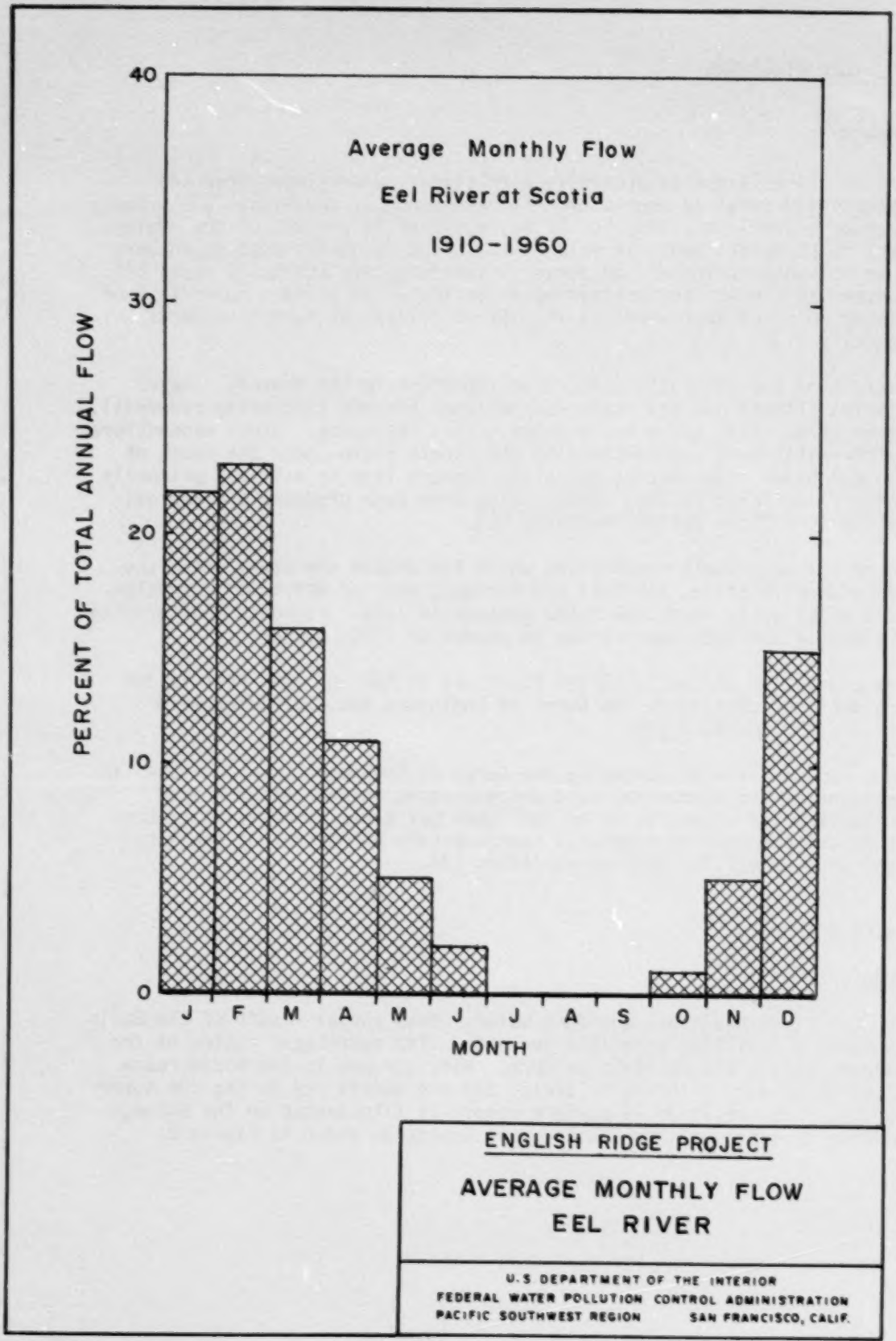
The population of the Eel River Basin was 39,850 in 1969. Population projections supplied by the Corps of Engineers are 45,730 for 1970 and 126,000 for 2020 [3].

Land use patterns projected by the Corps of Engineers show increases in residential and commercial land and decreases in agricultural land reflecting the urbanization of the lower Eel area. Commercial timberlands are expected to remain at approximately 60 percent of the total land area except for park acquisitions [3].

WATER RESOURCES

Supply

The Eel River Basin has abundant water. Mean annual runoff of the Basin is about 6.3 million acre-feet per year. The hydrologic regime of the streams follow the rainfall pattern. Many streams in the basin reach flood stage during the rainy period and are nearly dry during the summer months. The variation of surface runoff is illustrated by the average monthly discharge of the Eel River at Scotia as shown in Figure 2.



ENGLISH RIDGE PROJECT

AVERAGE MONTHLY FLOW
EEL RIVER

U.S DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC SOUTHWEST REGION SAN FRANCISCO, CALIF.

FIGURE 2

The most serious water problem of the basin is the periodic occurrence of damaging floods. Major floods occurred in 1907, 1938, 1959, 1955, and 1965, inflicting many millions of dollars worth of damage. Flood control needs, together with increased demand for water supplies and recreational facilities, are expected to lead to extensive development of the abundant, but relatively undeveloped, water resources of the Eel River Basin in the near future.

Additional water resources include four major ground water basins located in the Eel River Valley, Round Valley, Laytonville Valley, and Little Lake Valley. The storage capacity and the annual recharge of these four groundwater basins is shown in Table 1.

TABLE 1

MAJOR GROUND WATER BASINS[a/]

EEL RIVER BASIN

BASIN	STORAGE CAPACITY ACRE-FEET	ANNUAL RECHARGE ACRE-FEET
Eel River Valley	125,000	30,000
Round Valley	207,000	6,000
Laytonville Valley	18,000	15,000
Little Lake Valley	55,000	15,000

a/ U.S. Department of the Interior [4].

The Eel River Valley ground water basin includes an area above the confluence of the Van Duzen River and the Eel River Valley. Pumpage is estimated at 10,000 acre-feet per year. Recharge is taken directly from the Eel and Van Duzen Rivers. Safe yield is limited by salt water intrusion from the Pacific Ocean.

Round Valley has an area of 23 square miles and is located thirty miles north of Willits in Mendocino County. Pumpage from Round Valley ground water was estimated to be 2,000 acre-feet in 1954 [2].

Laytonville Valley occupies 12 square miles in north central Mendocino County around Laytonville. Ground water pumpage in 1954 was an estimated 900 acre-feet.

Little Lake Valley, slightly south of Laytonville Valley, has an area of 17 square miles around the town of Willits. Estimated ground water pumpage in 1954 was less than 500 acre-feet.

Water Uses

Water uses within the Eel Basin reflect the local timber and agriculture oriented economy and the substantial fishery resource. Principal water uses cited by the North Coastal Regional Water Quality Control Board in their 1965 report, "Water Pollution Control Objectives for the Eel River Basin," include....."domestic, municipal, agricultural and industrial water supply, fish and wildlife propagation and habitat, water oriented recreational activities including swimming, wading, boating and fishing plus certain aesthetic values," [5].

The present and estimated future water requirements for the Eel River Basin are listed in Table 2.

TABLE 2

PRESENT AND ESTIMATED FUTURE WATER REQUIREMENTS[a/]

EEL RIVER BASIN
(acre-feet/year)

WATER REQUIREMENTS	1960	1990	2020
Irrigation	26,070	74,130	105,460
Pulp & Paper (Heavy Ind.)	-	19,600	38,600
Municipal & Light Industry	5,200	11,000	24,300
Recreation	-	5,850	22,200
Total	31,270	110,580	190,560

[a/] State of California [2].

Fish and wildlife propagation is another major beneficial use of water within the Eel River Basin. In particular, the Eel River and its tributaries support salmon and steelhead fisheries that are among the largest in northern California and important sport and commercial fishing industries. Proposed water resource developments within the basin include provisions for release of water to maintain this fishery. Operation of English Ridge Reservoir will provide for annual fishery releases of 126,000 acre-feet. Proposed releases from Dos Rios Reservoir and Dinsmore Reservoir on the Van Duzen River may eventually provide additional fishery flows.

Quality

Runoff from the Eel River Basin has a low concentration of dissolved solids and is calcium bicarbonate in character. Mineral concentrations are within the U. S. Public Health Service recommended limits for drinking water. The range of water quality characteristics of the Eel River at Scotia is shown in Table 3

TABLE 3

SURFACE WATER QUALITY

EEL RIVER AT SCOTIA[a/]

CONSTITUENT[b/]	MAXIMUM OF RECORD	MINIMUM OF RECORD
Total Dissolved Solids	254	57
Specific Conductance (micromhos at 25°C)	441	98.0
Total Hardness as $CaCO_3$	212	43
pH	9.0	6.3
Temperature, °F	83	42
Dissolved Oxygen	18.2	6.2
Percentage Saturation	217	50
Turbidity, Parts Per Million	1,100	0.0
Coliform (Most Probable Number Per Milliliter)	7,000	0.045

a/ State of California [6].

b/ Concentration expressed as mg/l unless otherwise noted.

During periods of low flow, the boron concentration is high in the upper reaches of the Eel River. A maximum boron concentration of 4.2 mg/l has been recorded at Outlet Creek near Longvale [2]. However, this problem

is attributed to drainage from a small area and dilution in the Eel River reduces the boron concentration below the recommended maximum limits for Class 1 irrigation water.

The sediment load of the river is high during periods of highest runoff. During these periods the turbidity caused by the sediment load makes the water unsuitable for many uses. The deposits of sediment left when peak flows recede are detrimental to the spawning beds of the anadromous fishery. Federal and State agencies are presently conducting studies on the sediment problem in the Eel River and other basins in the North Coastal area. Formulation and implementation of watershed management practices to lessen the erosion problem will reduce damages and lower treatment costs of municipal and industrial water supplies.

Nutrient levels were low in the waters of the Upper Eel River sampled by Federal Water Pollution Control Administration during the summer of 1967. Nitrate and ammonia nitrogen concentrations were below detectable limits of 0.03 and 0.08 mg/l (N), respectively, and organic nitrogen values ranged from less than 0.08 mg/l to 0.17 mg/l (N). Total phosphorus values measured in 1967 were generally less than 0.01 mg/l (P).a/

The California Department of Water Resources has collected nutrient samples at various depths in Lake Pillsbury from March 1968 to May 1969. The average total nitrogen concentrations at the surface and near the bottom were 0.23 mg/l and 0.28 mg/l respectively. Average total phosphorus was 0.06 mg/l at the surface and 0.11 mg/l near the bottom.

Ground water in the Eel River Basin is generally of adequate mineral quality for most uses, although iron and manganese problems are present in some areas.

WATER QUALITY OBJECTIVES (STANDARDS)

The California North Coastal Regional Water Quality Control Board has established water quality control objectives for the Eel River Basin based upon the present and expected future beneficial uses. The beneficial uses to be protected include domestic, municipal, agricultural and industrial water supply, fish and wildlife propagation and habitat, water oriented recreational activities, and aesthetic values.

In order to provide optimum development of these beneficial uses the Board has established water quality criteria, that include the following [5]:

1) There shall be no direct discharge of untreated sewage to the waters of the Eel River, its branches or tributary streams.

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a/ Total phosphorus using persulfate method.

2) The discharge of sewage or industrial waste including agricultural waste shall not cause the dissolved oxygen content of the Eel River, its branches or tributaries to be reduced below a minimum of seven parts per million.

3) The five day BOD (biochemical oxygen demand) of sewage or industrial waste discharged to the Eel River, its branches and tributary streams shall not exceed 40 parts per million at any one time.

4) The discharge of sewage or industrial waste including agricultural waste shall not cause unsightly bottom deposits, slimes or fungus growths in the waters of the Eel River, its branches and tributary streams or increase the fertility of the receiving waters to the extent that an excessive growth of algae will result.

Dissolved oxygen (DO) concentrations used in this study as objectives for the evaluation of future flow requirements in the Eel River are 9 mg/l during November-April and 7 mg/l from May-October. In the Lower Eel River, downstream of the Van Duzen River, a DO of 7 mg/l will be necessary. The higher DO level used in this study reflects results of laboratory experiments with salmon embryo and the need for a safety margin to allow for DO fluctuations associated with the variability of natural runoff, indirect waste discharges and respiration of aquatic life [7,8,9]. The DO of the Eel River estuary must be maintained above 6 mg/l[a/], as stated in the Regional Board's Water Quality Control Policy for the Humboldt-Del Norte County Coast [5] which was subsequently adopted as a Federal water quality standard by the Secretary of Interior.

Maximum nutrient levels believed appropriate for the Eel River are 1.0 mg/l total nitrogen and 0.1 mg/l total phosphorus. Maintenance of nutrient concentrations below these levels should control nuisance growths of algae and aquatic plants within the flowing river. Similar objectives have been proposed in the Potomac River estuary for phosphorus and in the central portion of the Sacramento-San Joaquin Delta, and in the lower American River for nitrogen [10,11].

PROJECT IMPACT ON WATER QUALITY

The impact of additional water resource development upon the waters of the Eel River and the area affected by the trans-basin export route requires projection based on judgment and analysis involving many different scientific and socio-economic disciplines. The problem is one of projecting the future environmental quality produced by the development and routing schemes, interpreting the biological and human reactions to the altered water quality, and evaluating this reaction in monetary terms.

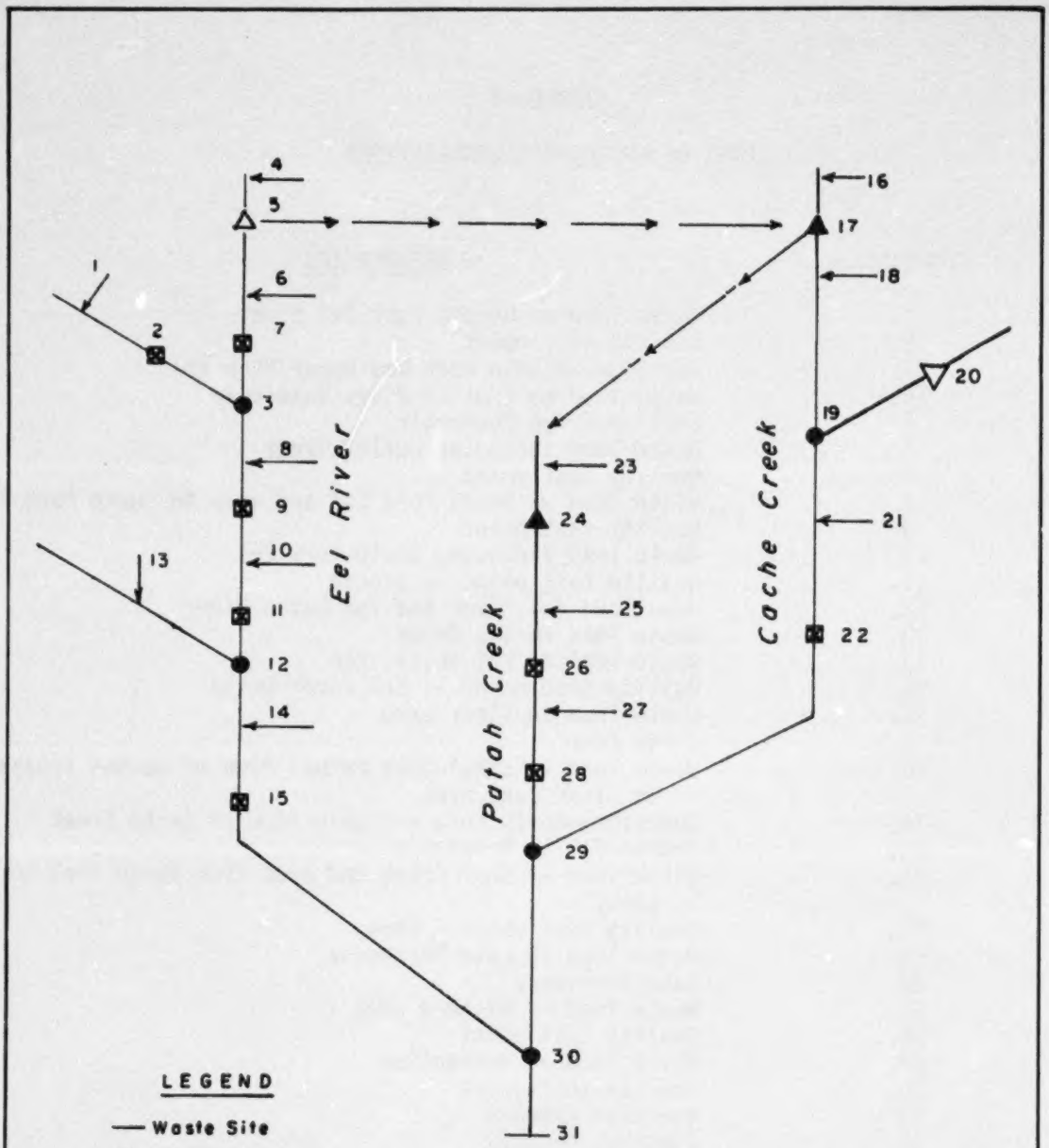
[a/] Average annual value - no single value below 5 mg/l.

Predictions were made of future water quality throughout the study area with and without the English Ridge Project for various waste treatment and disposal schemes. The predictive calculations were performed by a digital computer using a mathematical model of the Eel River and Putah-Cache Creek Basins. The water quality indicators investigated were nitrogen, phosphorus, total dissolved solids, and boron. The model structure allowed investigation of the effects of waste discharges from towns, industries, recreation and irrigation areas, and of reservoir operation and water resource management practices on the hydrologic and quality characteristics of the stream. Computer runs included both existing conditions, to verify input data and model operation, and reservoir releases and waste discharge schedules appropriate for future conditions.

Methodology

For each study, the system was first described by (1) its natural, unimpaired hydrologic regime, (2) evaporation and seepage conditions, and (3) its ambient water quality. A management plan was then imposed on this system consisting of (1) geometric locations of reservoirs, waste inputs and water uses, (2) a schedule of waste loadings from towns, industries, and irrigation districts, (3) a table of the capacities, downstream release and export schedules for the reservoirs, (4) water quality objectives, and (5) flow requirements and diversions. A detailed description of the model structure has been published previously [12].

A system of reservoirs, river reaches, diversions and waste discharges was formulated to represent the Eel River and Putah-Cache Creek Basins with the Pacific Ocean as the hypothetical end point. A representative diagram of the system is shown in Figure 3 and an accompanying list of coordinate descriptions is given in Table 4.



ENGLISH RIDGE PROJECT

REPRESENTATION OF SYSTEM INVESTIGATED

U.S DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC SOUTHWEST REGION SAN FRANCISCO, CALIF.

FIGURE 3

TABLE 4

LIST OF COORDINATE DESCRIPTIONS

COORDINATE	DESCRIPTION
1.	Waste load to Middle Fork Eel River
2.	Quality test point
3.	Junction--Middle Fork and Upper Main Eel
4.	Waste load to English Ridge Reservoir
5.	English Ridge Reservoir
6.	Waste load including Outlet Creek
7.	Quality test point
8.	Waste load -- North Fork Eel and area to South Fork Eel
9.	Quality test point
10.	Waste load including South Fork Eel
11.	Quality test point -- Scotia
12.	Junction--Eel River and Van Duzen River
13.	Waste load to Van Duzen
14.	Waste load to Eel Delta area
15.	Quality test point -- Eel River Delta
16.	Waste load to Clear Lake
17.	Clear Lake
18.	Waste load -- simulating return flow of wastes treated in Clear Lake area
19.	Junction--North Fork and main stem of Cache Creek
20.	Indian Valley Reservoir
21.	Waste load -- Bear Creek and area from North Fork to Capay
22.	Quality test point - Capay
23.	Waste load to Lake Berryessa
24.	Lake Berryessa
25.	Waste load -- Winters area
26.	Quality test point
27.	Waste load -- irrigation
28.	Quality test point
29.	Junction (Dummy)
30.	Junction (Dummy)
31.	End point

Thirty-seven years of monthly hydrologic data were routed through the system for each level of economic development, giving an indication of water quality to be expected during both wet and dry years. Stream flows and waste discharges were routed downstream from point to point, incorporating natural runoff with its associated ambient quality. Influent flows to the reservoirs and lakes in the system were added to the volume existing at the end of the previous month, and a new quality was determined based upon an assumption of complete mixing. Evaporation was accounted for, and each reservoir then made downstream releases and/or trans-basin exports according to its specified schedule, with releases being given priority over exports. All quality constituents were assumed to be conservative. Nutrient trapping and recycling in lakes and reservoirs were not modelled but these factors are considered separately. Desired flow and water quality objectives were specified at key locations. When flows or qualities did not meet desired objectives, the deficiencies were recorded at the test points and analyzed statistically at the end of each computer run.

An exception to the general reservoir operating criteria was Clear Lake which was considered subject to the Gopcevic Decree of 1920 [13]. This decree prohibits any withdrawal of water which would reduce its volume to less than 786,000 acre-feet and requires that water must be drawn from the lake in such a manner that its elevation on specified dates does not exceed the following percentages of the actual level on April 15th of each year:

Date	Percent of April 15 Level on Rumsey Gage
April 15	100%
May 1	97%
June 1	89%
July 1	79%
August 1	69%
September 1	58%

In this analysis, Eel River water was routed through Clear Lake in such a way that the volume of water in the lake was not significantly affected thereby, i.e., the import was balanced by additional export from the lake each month.

The principal output of the model was a statistical summary of hydraulic and water quality consequences of the implementation of the assumed water resource management system. Statistical moments and/or probability distributions were given for the following quantities.

1) Flows and flow deficiencies
2) Reservoir levels, evaporation, and exports
3) Pollutant concentrations and quality deficiencies

In addition, individual month-by-month values of concentration, flow or volume were printed for specified locations.

Systems Evaluated

A number of evaluations of future water quality were made based upon combinations of the following assumptions:

1) Two levels of economic development, i.e., those projected for the years 1970 and 2020;

2) Pre and post English Ridge reservoir conditions;

3) Export through Clear Lake of the 190,000 acre-feet yield of English Ridge Reservoir;

4) Two levels of nutrient removal from municipal-industrial wastewater throughout the entire system;

   (a) Conventional secondary treatment with removal efficiencies assumed as 50% for nitrogen and 30% for phosphorus;

   (b) Tertiary (advanced) treatment processed with removal efficiencies assumed as 80% for nitrogen and 90% for phosphorus;

5) Full wastewater collection around Clear Lake with discharge outside of the Clear Lake Basin and wastewater collection in the Lower Eel River area, with discharge to the Pacific Ocean. This would eliminate direct discharge of wastewater at the locations described in these particular areas.

Input Data

Hydrology: The monthly stream flows used in this study were unimpaired flows for the years 1915-16 to 1951-52 at the following reference locations:

1) English Ridge Damsite [14].
2) Dos Rios Damsite [14].
3) Scotia [2].
4) Bridgeville (Van Duzen River) [2].
5) Clear Lake [15].
6) Wilson Valley Damsite [14].
7) Monticello Dam [14].
8) Capay

Reservoir Data: Capacity of reservoirs in the Eel River Basin and on the export route are shown in Table 5.

TABLE 5

RESERVOIR SIZES

RESERVOIR	CAPACITY (1000 acre-feet)	DEAD STORAGE (1000 acre-feet)
English Ridge (proposed)	1,800	380
Clear Lake (existing)	1,100	786
Indian Valley (proposed)	300	4
Lake Berryessa (existing)	1,602	10

The schedule of diversions from English Ridge Reservoir to Clear Lake and its subsequent distribution is shown in Table 6.

TABLE 6

MONTHLY DISTRIBUTION OF ENGLISH RIDGE RESERVOIR EXPORTS

MONTH	DIVERSIONS FROM ENGLISH RIDGE RESERVOIR TO CLEAR LAKE	DISTRIBUTION OF ENGLISH RIDGE DIVERSIONS: CLEAR LAKE SERVICE AREA	UPPER PUTAH CREEK SERVICE AREA	SOLANO COUNTY SERVICE AREA	DELTA EXPORT
October	8,000	1,400	700	900	5,000
November	3,000	400	200	0	2,400
December	300	0	0	0	300
January	300	0	0	0	300
February	1,800	0	0	0	1,800
March	5,000	1,200	600	900	2,300
April	10,800	3,200	1,400	3,000	3,200
May	18,300	4,700	2,500	4,700	6,400
June	32,600	7,500	4,000	6,800	14,300
July	49,000	10,600	5,600	8,000	24,800
August	39,400	6,400	3,400	7,800	21,800
September	21,500	5,000	2,700	4,500	9,300
	190,000	40,400	21,100	36,600	91,900

The diversions listed in Table 6 for English Ridge Reservoir are averages of the 37 years of monthly exports to Garrett Tunnel obtained from the U. S. Bureau of Reclamation operation study of the reservoir, and were used in the mathematical model. The diversions from Clear Lake represent the deliveries to the Upper Putah Creek service area as part of the English Ridge Project. These diversions were combined or deleted as required by each individual study.

Average monthly schedules were used for required releases from English Ridge Reservoir to supply demands for fish maintenance, irrigation diversion, and other downstream water rights. The annual operation of English Ridge required a 174,800 acre-feet diversion to Potter Valley and a downstream release of 126,000 acre-feet in addition to the Garrett Tunnel diversions.

Waste Loads: Estimates of monthly waste loads for nitrogen, phosphorus, total dissolved solids, and BOD were made for various subdivisions of the study area for the years 1970 and 2020. These estimates were based upon projections by various state and federal agencies of future population, recreational use, and agricultural land use. Typical unit waste loads from domestic, industrial, recreational, and agricultural sources were utilized. Projected waste loads did not include background loads from natural runoff or drainage from undeveloped land areas. These loads were expressed by means of flow quality relationships for various sub-areas based upon available data. The development of projected annual nutrient loads included the consideration of measurements of nutrient contributions from agricultural land by Sylvester, Lackey, Sawyer, Eck, Weibel and others [16, 17, 18, 19, 20], and the types of agricultural development in the basins. Eel River Basin pastures and orchards were assumed to contribute nitrogen and phosphorus loads of 2.5 and 0.9 pounds per acre per year respectively and annual nutrient loads from field and truck crops in the Cache Creek, Putah Creek Basins were assumed as 17.5 and 2.5 pounds per acre per year respectively for nitrogen and phosphorus.

Weinberger et al [21] determined that the average annual nutrient load from domestic sewage in the United States is approximately 15 pounds nitrogen and 2.5 pounds phosphorus per capita. These figures were used to compute the nitrogen and phosphorus load from municipal sources and from recreational areas, with consideration given to the seasonal distribution of use.

The total dissolved solids waste load from municipal and recreational sources was computed by using 320 mg/l as a typical concentration of total dissolved solids in the effluent from a secondary treatment plant. Typically, the TDS concentration in irrigation return flow increases 2.5 times in surface return flow and 3.0 times in sub-surface return flow when compared with the concentration in the applied irrigation water.

The BOD waste load from municipal, industrial, and recreation sources was assumed to average 0.20 pounds per capita per day (ultimate) in the year 1970 and to increase to 0.25 pounds per capita per day in the year 2020.

Recreational, municipal and industrial waste loads were adjusted to reflect both various levels of treatment and possible collection and disposal systems. Present conventional secondary treatment plants are capable of 85% BOD removal, 50% nitrogen removal and 30% phosphorus removal. Efficiencies of 80% nitrogen and 90% phosphorus removal are expected to be possible by means of tertiary treatment in the future. BOD removal was assumed to remain constant for the study period. Complete diversion of sewered wastes can be accomplished along the Lower Eel River with ocean disposal and around Clear Lake, with disposal outside of the Clear Lake Basin.

Natural Runoff: The quality of natural runoff was expressed in the model studies either by a flow-quality relationship or as a constant background quality. The method used and the appropriate flow-quality relationship at each point in the system was based upon analyses of available data. The first method was used for TDS and boron except for the area around Clear Lake and Putah Creek, where constant concentrations were specified. The second method was used for nutrients throughout the entire system. Projected waste loads for different levels for development and various treatment and disposal practices were added to determine effects on water quality of the system.

The nutrients considered were nitrogen and phosphorus. Input concentrations were assumed representative of the dry weather season, which is the time when the major diversions from English Ridge Reservoir are scheduled. As determined by the California State Department of Water Resources, nutrient data for Lake Pillsbury for the period March to September, 1968 shows an average concentration of 0.30 mg/l total nitrogen at the surface and 0.33 mg/l near the bottom. Corresponding values of total phosphorus concentrations are 0.03 mg/l and 0.05 mg/l. However, field studies by FWPCA during the period from June to September 1967 revealed that total nitrogen and phosphorus concentrations in the Van Arsdale Diversion Reservoir and Lake Pillsbury were below detectable levels[a/] for all forms of nitrogen and phosphorus except for one value of 0.01 mg/l total phosphorus and two organic nitrogen values of 0.12 and 0.17 mg/l.

These reservoir values are considered to be the best available estimate of the actual background nutrient concentration of water that will flow into English Ridge Reservoir, from Lake Pillsbury located just upstream. Accordingly, the background nutrient content of the reservoir inflow was taken as 0.30 mg/l total nitrogen and 0.03 mg/l total phosphorus.

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a/ Detectable levels were as follows:

Nitrate-Nitrogen - 0.05 mg/l
Ammonia and Organic nitrogen - 0.08 mg/l
Phosphorus (total or ortho) - 0.01 mg/l

Reservoir Outflow

Entrapment of some portion of the inflowing nutrients will take place in English Ridge Reservoir which will tend to produce a lower nutrient content in the reservoir outflow. This entrapment is due to uptake by aquatic plants which are ultimately deposited in the bottom sediments of the reservoir. Some direct deposition also takes place, particularly in the case of phosphorus, much of which is tied to the suspended sediment flowing into the reservoir.

Not all of the nutrients which enter the bottom sediments of the reservoir are permanently lost, however. Under certain conditions some nutrients are recycled to the overlying waters and again become available for plant growth. The net effect of this removal and recycling is a net loss of nutrients from the water and a net gain by the sediments. The percentage of inflowing nutrients retained in a lake or reservoir is variable but a representative figure would be near 50% [42]. In this study, however, it was conservatively assumed that no retention would take place in the English Ridge Reservoir. Accordingly, the nutrient content of the reservoir inflow was considered to remain in the waters of the reservoir and to be present in its outflow.

Verification and Sensitivity

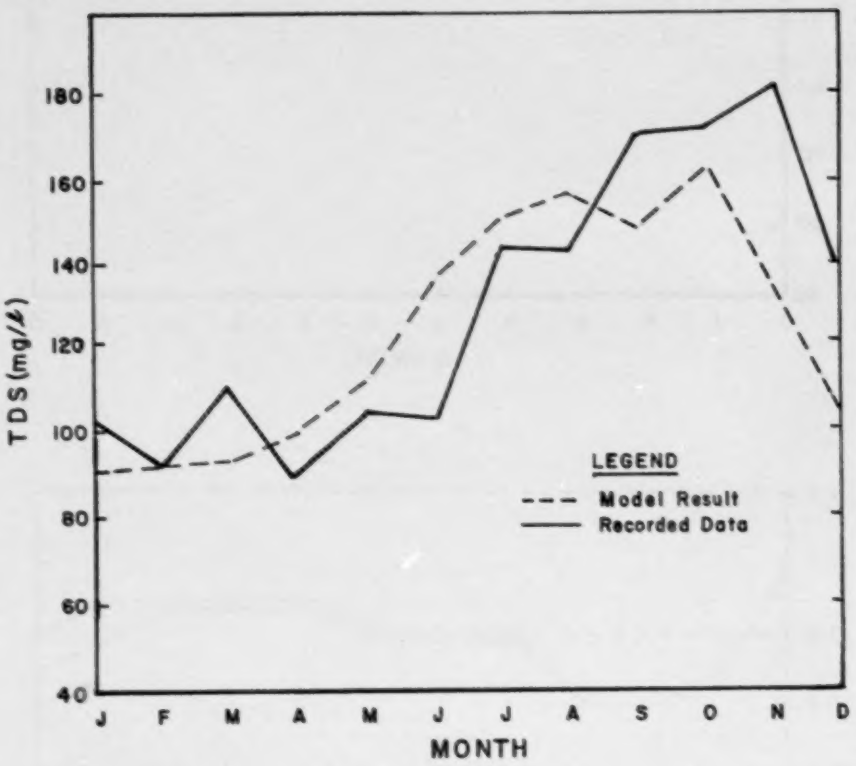
To verify the accuracy of the system model, a computer run was made to simulate present conditions. The predicted concentration of total dissolved solids in the Eel River at Scotia is compared to recorded data in Figure 4. Predicted concentrations of boron and total dissolved solids in Clear Lake are compared to recorded values in Figure 5. The correlation between observed and computed data is considered to be adequate.

The nitrogen concentrations predicted for Clear Lake ranged from 0.74 mg/l to 0.83 mg/l and averaged 0.79 mg/l. Phosphorus values ranged from 0.15 mg/l to 0.17 mg/l and averaged 0.16 mg/l. Predicted values for nitrogen and phosphorus closely approximate levels that have recently been found in Clear Lake.

Reservoir Water Quality

The predicted mean annual concentrations of nutrients in English Ridge Reservoir with secondary and tertiary levels of treatment of watershed waste loads in the years 1970 and 2020 are shown in Table 7.

These concentrations are within a range which is generally associated with lakes of pleasing aesthetic character. Therefore, recreational use of the project reservoir will not be significantly deterred due to undesirable conditions which accompany excessive nutrient levels.



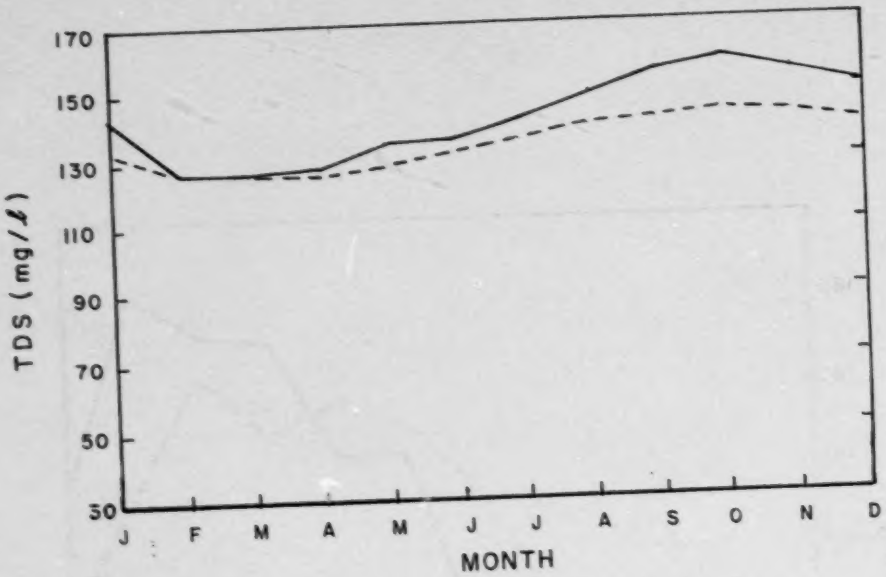
MEAN MONTHLY TDS CONCENTRATIONS
(Eel River at Scotia)

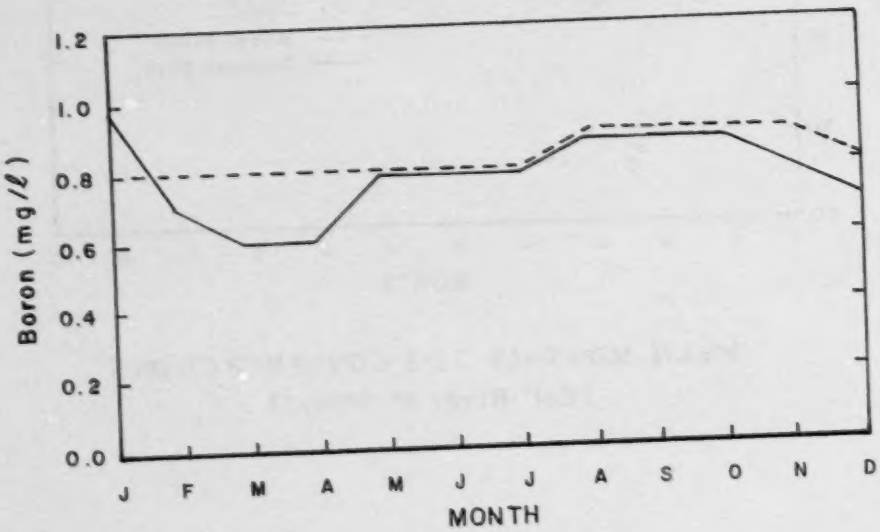
ENGLISH RIDGE PROJECT

MODEL VERIFICATION TDS
EEL RIVER AT SCOTIA

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC SOUTHWEST REGION SAN FRANCISCO, CALIF.

FIGURE 4





LEGEND

--- Model Result

—— Recorded Data

ENGLISH RIDGE PROJECT

MODEL VERIFICATION
TDS & BORON
CLEAR LAKE

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC SOUTHWEST REGION SAN FRANCISCO, CALIF.

FIGURE 5

TABLE 7

PROJECTED MEAN ANNUAL NUTRIENT CONCENTRATION

ENGLISH RIDGE RESERVOIR

LEVEL OF TREATMENT	1970 TOTAL NITROGEN MG/L	1970 TOTAL PHOSPHORUS MG/L	2020 TOTAL NITROGEN MG/L	2020 TOTAL PHOSPHORUS MG/L
Secondary [a/]	0.31	0.03	0.32	0.04
Tertiary [b/]	0.31	0.03	0.31	0.03

a/ Secondary Treatment

Nitrogen Removed	50%
Phosphorus Removed	30%

b/ Tertiary Treatment

Nitrogen Removed	80%
Phosphorus	90%

River Water Quality

Nutrients. Table 8 shows the projected water quality in the Lower Eel River in the year 2020 with English Ridge Reservoir in operation for secondary and tertiary levels of treatment.

The predicted quality of the Lower Eel River with English Ridge Reservoir in operation is superior to that predicted without the reservoir. The improvement is due to increased flow in the Eel River during the summer months as a result of releases from the reservoir. The projected mean annual nutrient concentration in the year 2020, in the Lower Eel is 1.03 mg/l total nitrogen and 0.30 mg/l total phosphorus without English Ridge Reservoir in operation and secondary treatment provided. The corresponding concentrations are 0.66 mg/l total nitrogen and 0.12 total phosphorus if tertiary treatment is provided.

With projected development of the Eel River Basin, it will eventually become necessary to lower the nutrient load discharged to the river to maintain the suggested criteria of 1.0 mg/l nitrogen and 0.1 mg/l phosphorus for a flowing stream. Advanced waste treatment and/or collection and disposal of domestic and industrial wastes in the Lower Eel by means of an ocean outfall are possible solutions. Available treatment methods appear adequate to maintain nutrient concentrations at a level which will not present a problem at present or in the near future. Improving

treatment technology may control nutrients before they become a problem in the Eel River Basin.

TABLE 8

PREDICTED WATER QUALITY

LOWER EEL RIVER

2020

QUALITY PARAMETER(MG/L)	SECONDARY TREATMENT[a]		TERTIARY TREATMENT[b]	
	Range	Mean	Range	Mean
Total Dissolved Solids	100-250	150	100-250	150
Nitrogen	0.34-1.60	0.76	0.32-1.02	0.53
Phosphorus	0.04-0.52	0.20	0.03-0.24	0.09
Biochemical Oxygen Demand	1-2	1	1-2	1
Dissolved Oxygen	8-11	10	8-11	10

a/ Secondary Treatment

Nitrogen Removal	50%
Phosphorus Removal	30%
Biochemical Oxygen Demand	85%

b/ Tertiary Treatment

Nitrogen Removal	80%
Phosphorus Removal	90%
Biochemical Oxygen Demand	85%

Suspended Sediment. Sediment transport in the Eel River Basin is an important water quality consideration. Typically, movement of sediment is directly related to the flow and, therefore, varies throughout the year. As proposed by the Bureau of Reclamation, English Ridge Reservoir will provide for an average annual loss of storage from sediment deposition of 250 acre-feet. As would be expected in a reservoir with a large capacity to average annual inflow ratios (2.8 at English Ridge), essentially 100 percent of the sediment inflow to the reservoir will be trapped. At the present time, it is estimated that Lake Pillsbury, located upstream from the proposed English Ridge Reservoir, entraps an average annual sediment load of 340 acre-feet or approximately 90 percent of the sediment inflow. Entrapment of sediments in English Ridge Reservoir will reduce the sediment load in the Eel River below the reservoirs. Reduced sediment loads will correspondingly reduce the turbidity of the water in the river during periods of high runoff. The magnitude of the reduction, which is in a large part dependent on the operation of the reservoirs and the multi-level outlets, is most difficult to evaluate. The problem is magnified further by difficulties in determining the degree of sediment pickup from river beds, after the release of clear water.

Data collected by the U. S. Geological Survey show that during certain years, Lake Pillsbury and Lake Mendocino, which receive water diverted from the Eel River, remain turbid after the winter runoff has subsided. This is due to the tendency of colloidal and organic material to remain suspended in reservoirs for prolonged periods. It is reasonable to expect that even with multi-level outlets the turbidity of water released from the project reservoir during the summer months may upon occasion exceed the turbidity found in pre-project conditions. However, it is difficult to accurately predict the turbidity of water to be released from the project reservoir. This should receive additional attention when the project is at the design stage in order to insure that the operation of the reservoir and the method of release selected will provide for the release of the best quality of water available.

The beneficial uses to be protected include domestic, municipal, industrial, and agricultural water supply, fish and wildlife propagation, water oriented recreational activities, and aesthetic values. Except for agricultural water supply these water uses would be adversely affected by increased turbidity during the summer months. Decreased turbidity and sediment loads during the winter runoff period would benefit the beneficial uses. An accurate estimate of the net effect of changes in turbidity and sediment load resulting from the project reservoir is not available at this time. The U. S. Geological Survey and the Soil Conservation Service are conducting field studies that will make additional data available in order to implement a management program.

Dissolved Oxygen. The proposed operation of English Ridge Reservoir provides for annual fishery releases of 126,000 acre-feet. The monthly distribution of fishery releases is shown in Table 9.

TABLE 9

PROPOSED FISHERY RELEASES

(Cubic Feet Per Second)

MONTH	ENGLISH RIDGE RESERVOIR
October	200
November	200
December	200
January	200
February	200
March	200
April	200
May	200
June	125
July	125
August	125
September	125

Estimates of gross cumulative flows in the Eel River necessary to maintain dissolved oxygen criteria for the critical period are shown in Table 10.

Operation of English Ridge Reservoir as proposed by the Bureau of Reclamation will provide for fish mitigation flow releases that will be in excess of flows required to maintain adequate dissolved oxygen concentration at all points in the Eel River except in the Lower Eel (River Mile 0 to 5) in the year 2020. Flow releases for fishery purposes from English Ridge will be in addition to tributary inflow, and it is anticipated that the minimum flow in the Lower Eel River will be in excess of that required to satisfy the dissolved oxygen concentration criteria.

TABLE 10

GROSS CUMULATIVE FLOWS REQUIRED
FOR WATER QUALITY CONTROL[a/]

(Cubic Feet Per Second)

LOCATION (MILES FROM MOUTH OF RIVER)	1960	2000	2020[b/]
0			
5	35	90	139
10	26	70	93
20	7	22	31
120	7	22	31

[a/] U.S. Public Health Service [22].

[b/] Flows for the year 2020 were obtained by projection.

Therefore, based upon present information, inclusion of separable storage for water quality in English Ridge Reservoir will not be needed. This conclusion is based upon the assumption that waste loads from projected developments will receive treatment equivalent to 85 percent BOD removal and tertiary treatment for removal of nutrients, and that the proposed releases to support the fishery use of the river will be made and maintained throughout the entire length of the Eel River.

Multi-Level Outlets

English Ridge Reservoir can be expected to stratify seasonally. Multi-level outlets will permit the withdrawal of water from various levels in order to obtain the best quality available. An adequate multi-level outlet structure is costly and such expense must be related to the beneficial effects of downstream water use. It is, however, extremely difficult to predict with a high degree of accuracy either the water quality conditions which may develop at specified depths in a large reservoir or the future specific downstream water uses and the associated

water quality requirements of these uses. The useful life of a large reservoir is normally very long and conversion of a single-level outlet after the reservoir is constructed is extremely costly. In many reservoirs adverse water quality conditions at various levels have developed which were not anticipated before construction. The risks and subsequent costs incurred with single-level outlets are considered greater than the insurance cost of including the multi-level outlet in the initial construction. For these reasons, it is recommended that multi-level outlets be provided at all locations where releases will be made.

Effects of Project Construction

During construction of the projects, adequate measures must be taken to protect both surface and ground waters. Provisions should be included in contract specifications so contractors will be cognizant of requirements to protect water quality in the work area in compliance with Executive Order 11288. Silt detention basins should be constructed at all work areas to prevent excessively turbid water leaching from earth work from entering surface waters. In equipment maintenance areas, special precautions should be taken to contain spilled fuel, lubrication products and wash water. Sewage from construction camps should be contained on land. All construction activities affecting water quality should comply with requirements of local and state water quality control authorities. Comments from the Federal Water Pollution Control Administration should be requested by the construction agency during the preparation of project plans.

VI. PUTAH-CACHE CREEK BASIN

ECONOMY

The southern export route involves diversion of water from English Ridge Reservoir through Garrett Tunnel to the Putah-Cache Creek Basin. It is also possible that future projects such as Dos Rios and Yellow Jacket will also utilize this route.

The Putah-Cache Creek Basin is economically dependent upon agriculture and recreation. Principal agricultural crops are alfalfa, pasture, pears, grain, sugar beets, walnuts, and grapes. Industrial activity is primarily limited to food packing and graveling operations.

Recreation is centered around Clear Lake. Activities such as boating, water skiing, swimming, fishing, and hunting attract many visitors from the metropolitan areas of San Francisco and Sacramento. In 1958, the total user days of water associated recreation at Clear Lake were estimated at approximately 2,300,000 with an estimated gross expenditure of 15 million dollars [23]. These figures are projected to reach 13.2 million user days by the year 2020, assuming water quality is not limiting.*

Population projections for the entire Putah-Cache Creek Basin range from 32,000 in 1970 to 69,000 in 2020. Present (1960) land use in the Putah-Cache Creek Basin includes approximately 46,000 acres of farmland, 40 percent of which are irrigated [24]. Urban and recreational lands are largely centered around Clear Lake.

WATER RESOURCES

Supply

Cache Creek at Yolo has an average annual runoff of 375,000 acre-feet of which 30,000 acre-feet are diverted between Capay and Yolo. Approximately ninety percent of the annual runoff occurs during the six-month period November to April [6]. The stream at Yolo is frequently dry from June to November. The monthly distribution of unimpaired annual flows of Cache Creek at Wilson Valley is shown in Figure 6.

The average annual safe yield of ground water service units in the Cache Creek Basin is shown in Table 13.

Flow in Cache Creek is regulated by the operation of Clear Lake as a reservoir and by irrigation diversions. Operation of the 1.1 million acre-foot lake allows 320,000 acre-feet regulation under terms of the Gopcevic Decree. The Decree regulates the seasonal variations allowed in the lake water levels between zero and 7.50 feet as measured on the Rumsey Gage located at Lakeport.

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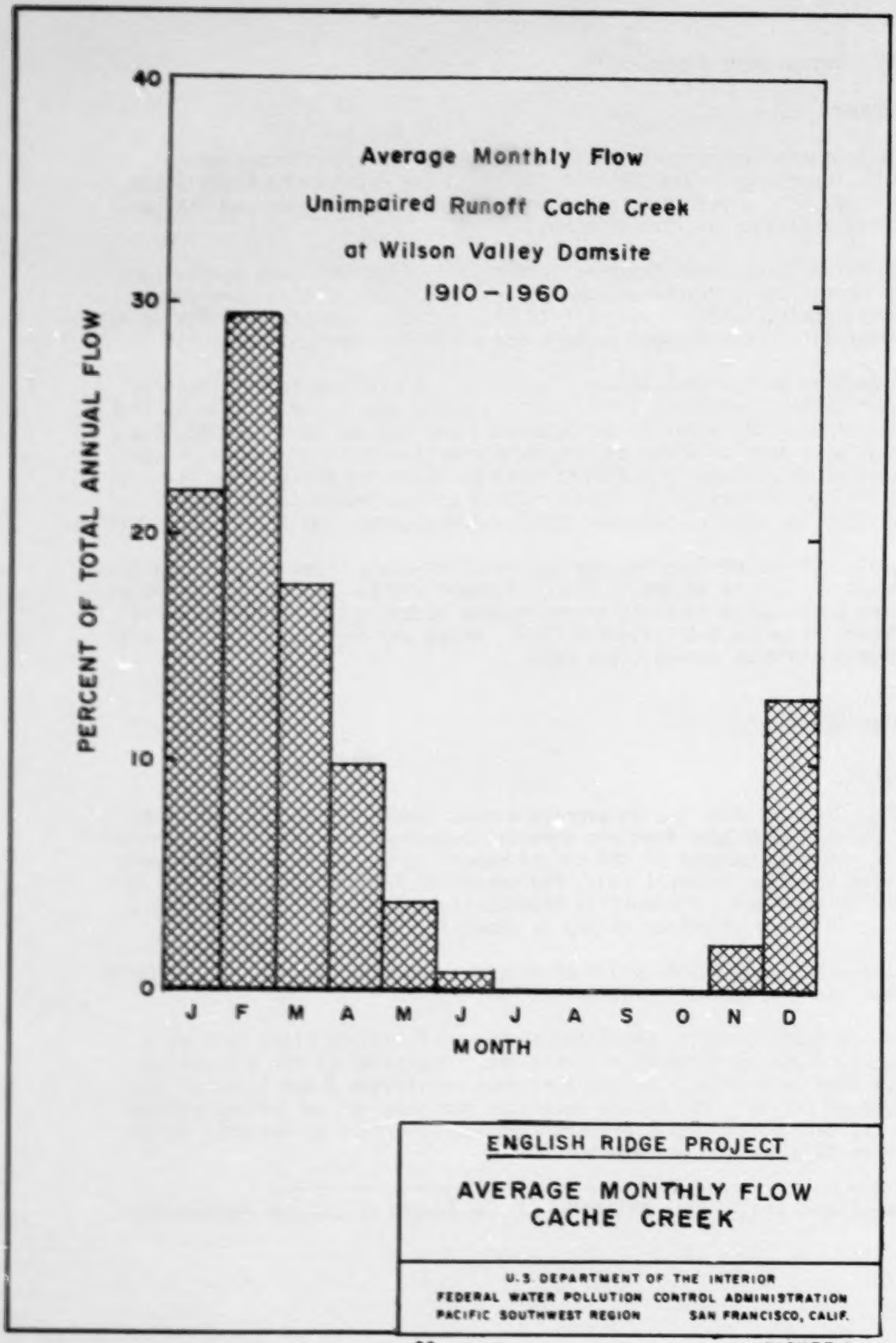
*Based upon preliminary estimates of the Bureau of Outdoor Recreation.



ENGLISH RIDGE PROJECT

AVERAGE MONTHLY FLOW
CACHE CREEK

U.S DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC SOUTHWEST REGION SAN FRANCISCO, CALIF.

FIGURE 6

TABLE 13

AVERAGE ANNUAL GROUND WATER YIELD[a/]

(Gross Pumping)

SERVICE UNIT	SAFE YIELD IN ACRE-FEET
Winters	81,000
West Hungry Hollow	5,000
East Hungry Hollow	18,000
Moore	75,000
Capay	10,100

a/ McCreary, Koretsky and Hill [15].

There are three major ground water basins in the Clear Lake Basin, Big Valley, Scott Valley and Upper Lake. These basins contain both free and confined aquifers and furnish most of the irrigation water in the area. Total storage capacity is estimated at approximately 130,000 acre-feet with a safe yield of about 37,000 acre-feet [25].

Putah Creek has a drainage area of 640 square miles with an unimpaired annual discharge of 344,900 acre-feet at the Monticello Dam. Monticello Dam forms Lake Berryessa, which has a storage capacity of 1,600,000 acre-feet and a firm annual yield of 206,000 acre-feet of which 181,000 acre-feet are diverted through the Putah South Canal for use in Solano County, and 25,000 acre-feet are for downstream use along Putah Creek.

The major ground water basins in Upper Putah Creek are the Collayomi-Long Valley and Coyote Valley. The storage capacities of these aquifers are estimated to total 63,000 acre-feet with a total annual yield of about 8,000 acre-feet [26].

Uses

The principal uses of water within the Putah-Cache Creek Basin are for recreation, irrigation, and domestic purposes. Agriculture is by far the largest user of water. The probable ultimate total seasonal amount of water required in the Clear Lake area for agriculture is estimated by the Bureau of Reclamation at approximately 66,000 acre-feet per year [27].

In the Lower Putah-Cache Creek Basin 315,000 acre-feet were used in 1963 and annual requirements are expected to increase to 389,000 acre-feet by the year 2020 [28]. In the Upper Putah Creek Basin 8,250 acre-feet were used in 1963 and demand is estimated to increase to 20,000 acre-feet per year by the year 2020.

In 1965, the domestic water requirement for the Clear Lake area totaled 2,600 acre-feet. Approximately 25 percent was derived from Clear Lake and the remainder from tributary streams and wells [29]. Domestic water in the remaining Cache Creek area comes from ground water. The annual requirement for municipal and industrial purposes was estimated at 8,400 acre-feet in 1963 and is projected to increase to 44,000 acre-feet by the year 2020 [28].

Recreation in the lower Cache Creek Basin is limited primarily to fishing and hunting. Development of proposed water resource projects such as Indian Valley Dam will enhance the recreation potential. Releases from the reservoir include provision for a minimum flow of 10 cfs, to maintain sport fisheries on the North Cache Creek and Cache Creek.

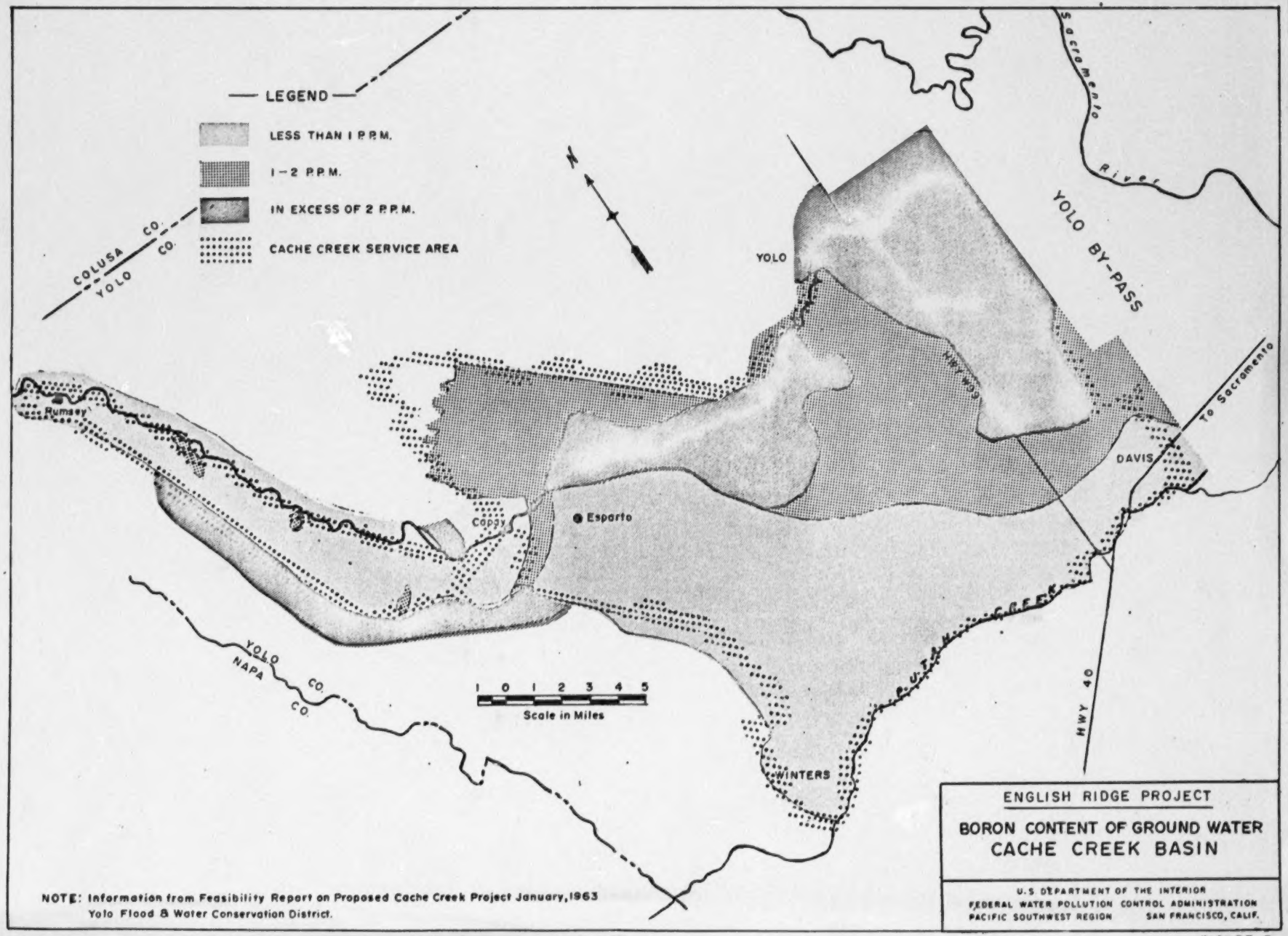
Quality

Water quality within the Putah-Cache Creek Basin is characterized by high boron levels in ground and surface waters and by intense eutrophication of Clear Lake. Eutrophication is characteristic to a much lesser extent of other large lakes in the basin.

Surface and ground waters are characteristically a magnesium-calcium bicarbonate type with boron concentrations often in excess of 0.5 mg/l, the upper limit for Class 1 irrigation water. Boron concentrations as high as 5 mg/l have been reported in Cache Creek near Capay. The boron content of ground water is shown in Figure 7. Total dissolved solids concentrations above 500 mg/l have been reported in Cache and Putah Creeks.

Coliform counts in Clear Lake are in excess of desirable levels for activities involving water contact. The County Health Officer has indicated that failure to provide adequate treatment for wastes may result in bacterial levels making it necessary to prohibit use of the lake for water contact recreation [30].

Clear Lake and Cache Creek are fed by small streams and springs that have a very high boron concentration. The mean annual boron concentration of 0.9 mg/l in Clear Lake and 1.1 mg/l in Cache Creek at Capay during the irrigation season are in excess of the Class 1 standard for irrigation water. The boron concentration of ground water in the Cache-Putah Creek Basin is well in excess of the standard for Class 1 irrigation water and much of the area falls into the Class 3 or "injurious to unsatisfactory" class.



NOTE: Information from Feasibility Report on Proposed Cache Creek Project January, 1963
Yolo Flood & Water Conservation District.

FIGURE 7

Clear Lake is objectionably eutrophic during certain seasons of the year.* Clear Lake has long had nuisance level crops of blue green algae, principally Aphanizomenon, Anabaena and Microcystis. The most objectionable aquatic plant growths are probably the blue green algae which often are present as unattractive malodorous, floating scums. In general they are inferior as a food source for aquatic fauna and some blue green algae are toxic to warm blooded animals that ingest the water. The Lake attracts a large recreational population in the spring, but loses many recreationists in late summer and early fall as a result of the nuisance conditions.

The enrichment of Clear Lake has been related to nitrogen and phosphorus contributions from agricultural and other land drainage and from domestic sewage. Waste water from approximately 30 percent of the Lake's resident and resort population receives secondary treatment with effluent applied to land; the remainder are serviced by septic tanks many of which are known to drain either directly or indirectly to the lake [29].

Water quality within Clear Lake and in the upper Eel River was investigated by FWPCA personnel through limited field studies during the summer of 1967. An evaluation was made of certain chemical and physical data gathered by the California Department of Water Resources during 1964 and 1965, [31] and physical and biological measurements were made by the Lake County Mosquito Abatement District between 1963 and 1967.

The FWPCA data compared the nutrient content of the various waters with the algal crops and transparency. Sampling was confined to the near surface waters. Lake sampling station locations are shown on Figure 8. No attempt was made to carry out a nutrient budget or characterization of the lake sediments in this limited survey.

Nutrient data for the entire water column collected by the California Department of Water Resources (DWR) have been examined. The laboratory analyses reported between April 20 and June 8, 1965 averaged 1.2 mg/l total nitrogen and 0.11 mg/l total phosphorus [31]. Values reported by DWR prior to April 20, 1965 were not considered since organic nitrogen was not included and other nitrogen measurements were based on field analyses.

The nutrient levels found in the FWPCA surveys during 1967 documented the nutrient concentration present in the upper waters during July when floating algae were not a problem. Total nitrogen and phosphorus averaged 0.56 and 0.06 mg/l respectively for six samples gathered during the July survey and during a reconnaissance survey in June. Lake surface levels were higher in June and July 1967 than in 1965 as a result of heavy spring rains.

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*Eutrophic is derived from the Greek, ευτρὸφόσ, meaning essentially "well nourished." Liddell and Scott, Greek-English Lexicon, New York 1846.

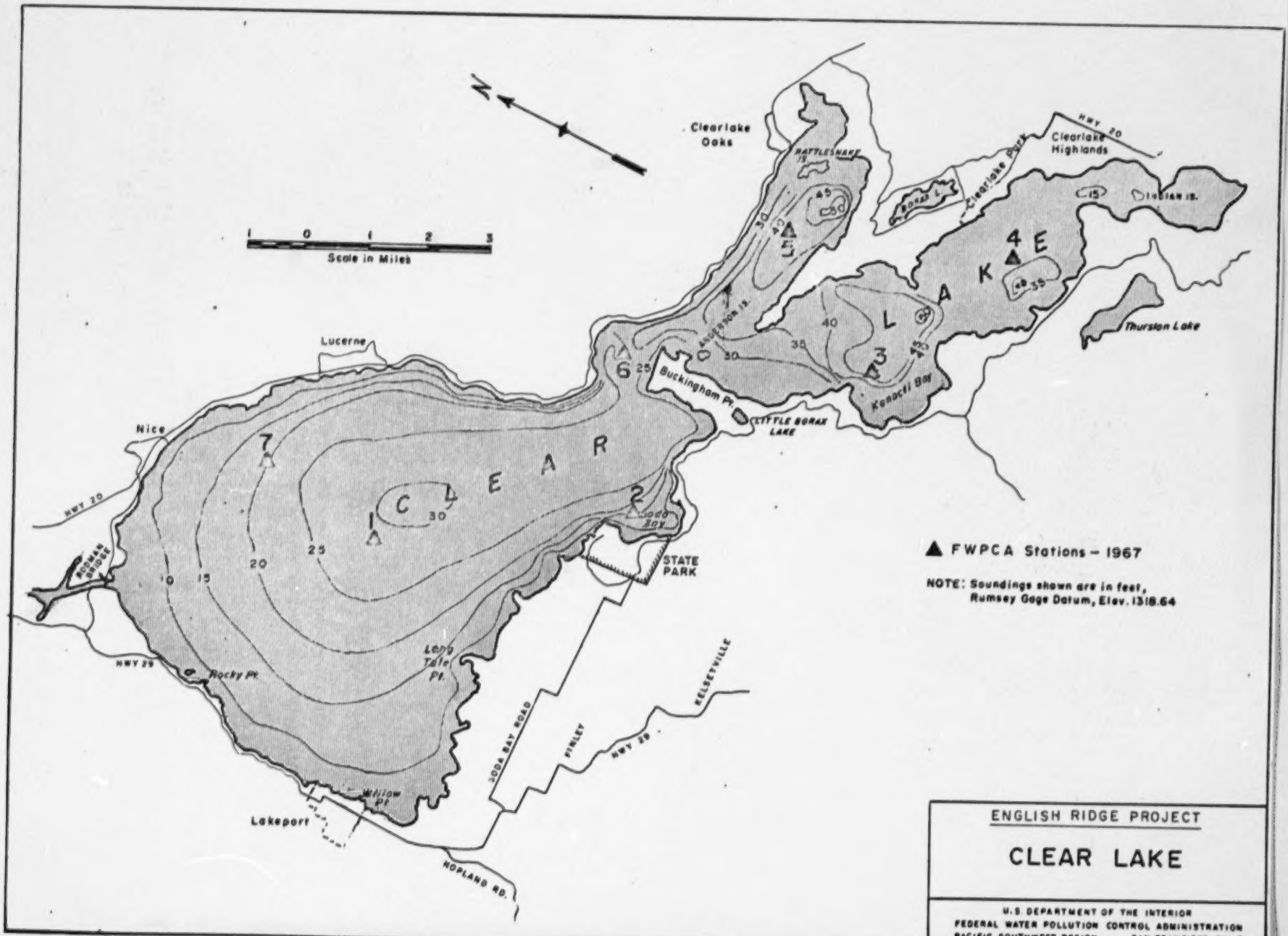

N
Clearlake Oaks
Clearlake Highlands
Clearlake Park
HWY 20
RATTLESNAKE I.
BOGGS I.
INDIAN IS.
Scale in Miles
1 0 1 2 3
LAKE
Thurston Lake
Lucerne
Buckingham Pt.
LITTLE BORAX LAKE
Konocti Bay
Nice
CLEAR
Soda Bay
STATE PARK
HWY 20
ROSSMAN CREEK
HWY 29
Rocky Pt.
Long Tule Pt.
Willow Pt.
Lakeport
SODA BAY ROAD
FINLEY
HWY 29
KELSEYVILLE
HOPLAND RD.
▲ FWPCA Stations – 1967
NOTE: Soundings shown are in feet, Rumsey Gage Datum, Elev. 1318.64
ENGLISH RIDGE PROJECT
CLEAR LAKE
U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC SOUTHWEST REGION SAN FRANCISCO, CALIF.

FIGURE 8

Lake algal populations in June and July were dominated by Aphanizomenon, a blue green alga common in enriched lakes. No surface scums were found in the main body of the lake.

During July 1967, a reconnaissance survey was made of the lake shore around the State Park in Soda Bay. Some filamentous algal growths were found near shore including floating Rhizoclonium mats and Cladophora attachments on submerged stones. The water had a green cast and a milky turbidity. The dominant emergent vegetation was cattails, but the stands were not dense.

In August 1967 the blue green alga Microcystis was dominant in the Lake. Scum formations were evident along the lake shore and in surface waters of small coves and embayments, but the open waters of the lake were generally free of floating mats. Evidence of a blackfish kill was sighted near Lucerne. Blackfish are plankton feeders.

In September 1967, dense algal crops were reported during the Labor Day weekend and an extensive fish kill had occurred throughout the lake. Surface scums of living and decomposing algae were evident. The September field survey reaffirmed the nuisance conditions and crops of Microcystis and Anabaena were found throughout the lake. High organic nitrogen levels (1-4 mg/l) were found in the upper waters of the lake. Decomposing fish and algal scums were observed and photographed.

Chlorophyll levels from near surface grab samples in the Lake were generally less than 50 µg/l during June, July and August whereas most exceeded 300 µg/l in September. Monthly plankton tow records of the Lake County Mosquito Abatement District show that Aphanizomenon, Microcystis, and Anabaena populations have dominated the net phytoplankton since at least 1963. Similar data on Lake Berryessa demonstrated the presence of blue green algae in considerably lesser concentrations. Lake Berryessa and the Blue Lakes of Lake County do not exhibit the extreme eutrophication symptoms found in Clear Lake.

WATER QUALITY OBJECTIVES (STANDARDS)

The Central Valley Regional Water Quality Control Board is charged with the responsibility of regulating waste discharges in the Clear Lake Basin and Cache and Putah Creeks. The major beneficial water uses include domestic and industrial water supply, irrigation and stock watering, fish propagation, and recreation. The Board is in the process of reviewing its policy and long range plan for water quality control in this basin. At the present time, the Board provides for individual discharge requirements on a number of waste dischargers.

Agriculture and recreation are the major beneficial water users in the Putah-Cache Creek Basin. Quality criteria for irrigation water cannot be reduced to absolute limits because of the variability associated with soil types, climatic conditions, irrigation practices and crop sensitivity.

To be acceptable for recreational use involving water contact sports, water must be aesthetically enjoyable, free from toxic substances, and reasonably free from bacteria indicative of human wastes. Water quality criteria and waste discharge regulations should provide a water that is not dangerous to the health of recreationists participating in water contact activities and also reasonably free from excessive biological productivity.

A warm water fishery is present in Clear Lake. Warm water fish are tolerant to temperatures above the mid-seventies and dissolved oxygen levels somewhat below 5 mg/l. If a trout fishery is to be maintained on Cache and Putah Creeks, it will be desirable to maintain dissolved oxygen levels of 7 mg/l and temperatures below 70 degrees Fahrenheit.

Nutrient criteria may be selected that describe natural lakes of generally pleasing character. Hutchinson has cited phosphorus levels of 0.01-0.03 mg/l as typical of clean lakes [32], Lackey and Sawyer have recommended 0.015 mg/l PO_4-phosphorus and 0.30 mg/l inorganic nitrogen as maximum levels to be present at the time of spring overturn in the lakes they studied in Wisconsin, if nuisance growths of algae are to be avoided [17]. Mackenthun has suggested a water quality of 0.02 mg/l total phosphorus for Lake Sebasticook, Maine [33]. The Lake Erie Enforcement Conference Technical Committee has recommended water quality objectives of 0.015-0.025 mg/l total PO_4-phosphorus and 0.30 mg/l total inorganic nitrogen for Lake Erie [34]. Sylvester has suggested that undesirable algal crops and taste and odor problems were accompanied by combinations of nitrate plus ammonia nitrogen levels and combined tannin and lignin levels when each rose above 0.50 mg/l [35].

Stewart and Rohlich describe various lake classifications ranging from eutrophic to oligotrophic types including a mesotrophic type defined as of intermediate nutrient content [36]. Yoshimura classified mesotrophic Japanese lakes as having .022-.044 mg/l P_2O_5-P and 0.1-0.2 mg/l total nitrogen [37].

Nutrient criteria considered for evaluation of predicted water quality changes in Clear Lake are not fixed on any one set of nitrogen or phosphorus concentrations, but instead recognize that summer algal crop levels will diminish or flourish at nuisance levels less frequently as concentrations of both elements are lowered. Control of biological productivity at a level that is compatible with all water uses may indeed be impossible. However, overall improvements for all uses can be expected should existing nutrient levels be lowered from 0.5-1.0 mg/l toward 0.1-0.3 mg/l total nitrogen and from 0.05-0.10 mg/l toward 0.01-0.03 mg/l total phosphorus.

PROJECT IMPACT ON WATER QUALITY

Predicted Water Quality

Projected mean annual concentrations of nitrogen, phosphorus and total dissolved solids for various levels of treatment both with and without English Ridge imports to Clear Lake are shown in Table 12. These projected values were obtained from the computerized analysis described in Chapter V.

Based upon projected future waste loads and continuation of present treatment methods, the mean annual concentrations of 0.79 mg/l total nitrogen and 0.16 mg/l total phosphorus projected in Clear Lake in the year 1970 will increase to 1.09 mg/l of nitrogen and 0.29 mg/l of phosphorus by the year 2020.

Provision of advanced waste treatment of waste loads would reduce the mean annual concentrations of total nitrogen and phosphorus to 0.66 mg/l and 0.10 mg/l respectively in the year 1970, and to 0.83 mg/l and 0.16 mg/l in the year 2020.

If domestic wastewaters are collected and transported out of the Clear Lake basin, the total nitrogen and phosphorus concentrations would be 0.60 mg/l and 0.07 mg/l respectively in 1970, and 0.68 mg/l and 0.14 mg/l in the year 2020.

Diversion of Eel River water through Clear Lake would reduce the nutrient levels cited above. If, for example, present treatment methods are continued, importation of 190,000 acre-feet of water from English Ridge reservoir each year would lower the nutrient concentrations by 30 to 45%. The nutrient concentration in Clear Lake would be reduced to even lower levels if water from future Eel River developments such as the Dos Rios and Yellow Jacket projects was routed through Clear Lake, in addition to the English Ridge import considered here. The degree of improvement would be dependent upon the total amount and quality of water imported and the method of operation of the projects.

The water imported to the Clear Lake Basin from the Eel River Basin will have a boron concentration in the range of 0.10 to 0.15 mg/l. If water from the English Ridge project were routed through Clear Lake and Cache Creek, the concentration of boron in each of those waters would be reduced as shown in Table 13.

Variations in concentrations in Clear Lake through the year are expected to be quite small for all constituents based upon the computerized analysis described in Chapter V. Calculated monthly mean boron concentrations during the irrigation season never differed by more than 0.02 mg/l from the annual mean, although the variation between wet and dry years was about twice this difference. Maximum variation of nutrient concentrations always occurred with minimum waste treatment but even under 2020

TABLE 12

PROJECTED MEAN ANNUAL QUALITY OF CLEAR LAKE WATER

Level of Import (AF/YR)	Wastewater Treatment Levels[a]								
	50-30% Removal[b]			80-90% Removal[c]			No Waste Discharge to the Lake[d]		
	TDS (mg/l)	N (mg/l)	P (mg/l)	TDS (mg/l)	N (mg/l)	P (mg/l)	TDS (mg/l)	N (mg/l)	P (mg/l)
1970 LEVEL OF DEVELOPMENT									
None	150	0.79	0.16	150	0.66	0.10	150	0.60	0.07
190,000	110	0.56	0.09	110	0.49	0.06	110	0.45	0.05
2020 LEVEL OF DEVELOPMENT									
None	260	1.09	0.29	260	0.83	0.16	260	0.68	0.14
190,000	180	0.75	0.18	180	0.60	0.10	180	0.51	0.10

[a] Recreational, municipal and industrial wastes discharged to Clear Lake after indicated treatment.

[b] 50% removal of total nitrogen; 30% removal of total phosphorus (secondary treatment).

[c] 80% removal of total nitrogen; 90% removal of total phosphorus (tertiary treatment).

[d] Export of M&I and recreational waste out of Clear Lake Basin.

TABLE 13

PREDICTED BORON CONCENTRATIONS IN CLEAR LAKE AND CACHE CREEK

1970

LEVEL OF IMPORT (AF/YEAR)	CLEAR LAKE (MG/L)	CACHE CREEK AT CAPAY (IRRIGATION SEASON) MG/L
None	0.9	1.1
190,000	0.5	0.7

development the highest total nitrogen and total phosphorus average monthly values were only 0.09 and 0.01 mg/l greater than the respective annual mean concentration.

The entry of Eel River water would be expected to result in temperature changes in Clear Lake. The magnitude of the change will be dependent upon the quantity of water diverted and the depth at which it is withdrawn from the reservoir. Studies by the Department of Water Resources [49] led to the conclusion that with the proposed English Ridge diversion the temperature of Clear Lake water would most probably be lowered by about 2°F in August though the resulting temperature drop could conceivably be as much as 8°F. Such temperature changes were not considered sufficient to adversely affect the beneficial uses of Clear Lake.

Suspended inorganic sediments transported from the Eel River watershed may cause increased turbidity in Clear Lake. Any such increase will depend on the extent to which the proposed reservoir effects the removal by settling of sediments carried by turbid winter and spring inflows, and on the effectiveness of multi-level outlet structures to permit withdrawal of the clearest water available in the reservoir. While these considerations are most difficult to evaluate, it would seem that some increase in Clear Lake turbidity could be expected.

The English Ridge Project, as proposed by the Bureau of Reclamation, would divert approximately 21,000 acre-feet of water into the Putah Creek Basin. Routing this water through Clear Lake and into Putah Creek Basin will increase the nutrient load entering Monticello Reservoir. However, the effect of the relatively small quantity of water involved in the transfer on the nutrient level in Monticello Reservoir was undetectable in the model analysis. The Bureau would route 37,000 acre-feet of water to Solano County via canals on the west side of the Sacramento Valley. Diversion of this water to Solano County via the canals will make it unnecessary to route the water through Lake Berryessa, thus reducing the nutrient load entering the lake.

Exportation of Eel River Basin water to the Sacramento River through Clear Lake would not significantly change the concentrations of nutrients, boron or TDS in the Sacramento River and would not interfere with beneficial use of Sacramento River or Delta waters. The increase in total nitrogen and phosphorus concentration in the Sacramento River would average 0.5% and boron concentration 0.004 mg/l.

Nutrients and Lake Sediments

Lakes trap and retain nutrients in bottom sediments. Under certain circumstances these nutrients may be recycled from the sediments back to the overlying waters. Lake sediments, therefore, represent an important potential source of nutrient materials. The importance of this source of stored nutrients in Clear Lake must be considered in attempting to predict the consequences of diverting Eel River water through the Lake.

Several studies cited by Mackenthun [42] indicate that a significant portion of the nutrients entering a lake eventually become part of the bottom sediments. In a few cases the percent retention of nutrients reached 80 to 90 percent. Nitrogen and phosphorus analyses from lake sediments listed in Table 14 demonstrate this nutrient trapping principle.

TABLE 14

NITROGEN AND PHOSPHORUS

IN LAKE BOTTOM SEDIMENTS

LAKE	SOURCE	NITROGEN (%)	PHOSPHORUS (%)
Sebasticook (Maine)	FWPCA [33]	.3-1.8 a/	.06-.16
Tahoe (Calif.-Nev.)	McGauhey [43]	.6-1.6	-------
Madison Lakes (Wis.)	Sawyer [44]	.7-.9	.10-.12
Green Lake (Wash.)	Sylvester and Anderson [45]	.6	.17
Klamath Lake (Ore.)	FWPCA [46]	.34	.16
Clear Lake (Calif.)	DWR [31]	.7 b/	.07

a/ Organic Nitrogen Values

b/ Mean value calculated from data in Bulletin 143-2 of the California Department of Water Resources [31].

In addition to the data tabulated above, Mackenthun cited a range of 0.55-3.58 percent organic nitrogen from 39 lakes in Wisconsin and Alaska as reported by Juday et al [47]. Many of these 39 lakes were not eutrophic and certainly Lake Tahoe (Table 14) is not considered eutrophic. The similarity of nutrient concentrations from lakes of differing levels of enrichment suggests that the percentage of nitrogen or phosphorus present in lake sediments is not necessarily a valid index of the extent of eutrophication of the lake's waters.

The resolution of phosphorus from bottom sediments is linked with the oxygen content of the bottom waters and the special chemistry of iron. Under well-oxygenated conditions, iron compounds are insoluble and phosphorus is bound up as insoluble ferric phosphate. As oxygen levels fall to near zero, ferric compounds are reduced to soluble ferrous forms and phosphorus can then be released from the sediments. This sequence probably does not often occur at the mud-water interface in Clear Lake since it is relatively shallow and well mixed.

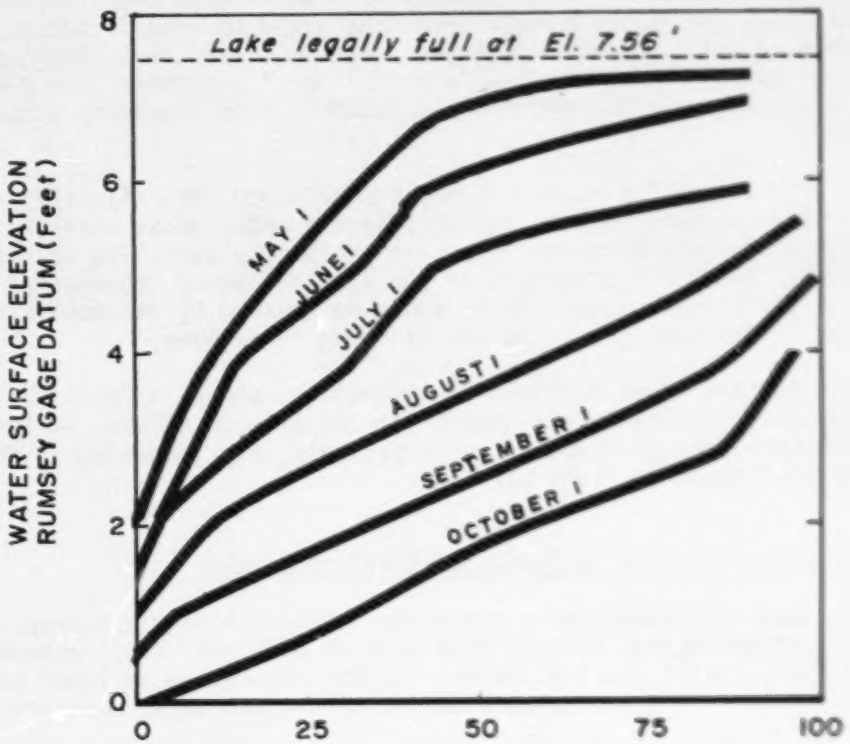
The upper seven feet of Clear Lake is operated as a reservoir. The mean depth is approximately 26 feet before any drawdown occurs, corresponding with a Rumsey gage reading of 7.56 feet. Figure 9 shows the frequency of occurrence of various Rumsey gage heights during the dry weather season (May-October) for the past 30 years. These curves show that lake levels in October are about six feet lower than May in 50% of the 30 years.

In lakes where thermal stratification occurs dissolved nutrients may be retained in the deeper, colder waters until physical forces break up the thermocline. Clear Lake rarely stratifies thermally except for brief periods in the deepest parts. High water temperatures prevail in summer and strong winds help to mix oxygen throughout the lake waters.

A significant portion of the nutrients entering bottom sediments are not recycled but are permanently retained. Most of the carbon, nitrogen and phosphorus in a 19 inch core from Lake Sebasticook, Maine lay below the upper two inches in the sediments, although concentrations were higher in the more biologically active layers near the mud-water interface. The buildup of organic matter in permanent lake sediments can be further demonstrated by oil and coal deposits, comparisons of geologically old and young lakes and the rich sediments in sewage ponds.

Several eutrophic lakes have been improved by controlling nutrient inputs in spite of the presence of nutrient rich sediments. Qualitative improvements have been reported at Lake Monona, Wisconsin, and Lake Washington, near Seattle where domestic sewage inflows were collected and transferred to disposal sites outside the drainage basin of these lakes [48].

Nutrient material in bottom sediments apparently did not prohibit water quality improvement. Recycling of nutrients, particularly phosphorus, is known to be important in maintaining algal populations; however, it is not believed that this mechanism can, of itself, maintain the extremely dense algal crops in Clear Lake waters.



FREQUENCY* OF OCCURRENCE OF CLEAR LAKE WATER LEVELS
(Percent)

NOTE: Curves based on data made available by the Lake County Flood Control and Water District for the years 1938-1967

* Percentage of time water levels equal or less than values shown on first day of month

ENGLISH RIDGE PROJECT

CLEAR LAKE WATER LEVEL FREQUENCY DIAGRAM

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC SOUTHWEST REGION SAN FRANCISCO, CALIF.

FIGURE 9

Much additional research will be required to be able to accurately describe the nutrient retention - recycling relationships of the waters and sediments of lakes and reservoirs. Based upon the information available, however, it would seem reasonable to expect that a significant amount of nutrient trapping takes place in Clear Lake. While conditions do not appear favorable for the recycling of nutrients from the sediments of Clear Lake, this phenomenon undoubtedly also occurs to some unknown extent.

For purposes of this study it has been assumed that all nutrients entering the lake will be retained in the water phase whether through deposition and subsequent recycling or through recycling in the water column. Nutrients presently in the lake sediments are assumed to be unavailable since these layers would be covered by new deposits of organic detritus. Thus, no net trapping is assumed.

The expected future nutrient concentrations given in Table 12 were determined employing this assumption and are, therefore, believed to be reasonable, though probably conservatively high estimates of future nutrient levels in Clear Lake.

Biological Response to Predicted Nutrient Levels

Clear Lake nutrient levels presently are in the highly eutrophic range with concentrations varying from 0.05 to 0.10 mg/l total phosphorus and 0.50 to 1.2 mg/l total nitrogen. Higher levels can be found near the lake surface in summer when floating blue-green algae mats are present.

Symptoms of eutrophication are present in other lakes in the north coast area, such as Lake Pillsbury, Lake Mendocino and Lake Berryessa. Data from the Lake County Mosquito Abatement District indicate that algal crops measured by vertical plankton tows (20 feet) are generally less than 0.5 ml in lakes Pillsbury and Berryessa, where the blue-green alga Aphanizomenon has been reported. Clear Lake phytoplankton tow measurements made between 1963-1967 are generally between 1.0-5.0 ml during summer although volumes exceeding 100 ml have been recorded. Dinoflagellate blooms, notably Ceratium, have been reported in Lake Mendocino. Ruth Reservoir, located in a remote area in the Mad River drainage, does not exhibit nuisance algal blooms. The geology of the Ruth Reservoir area is similar to the upper Eel drainage. Many of these lakes can be termed mildly eutrophic because symptoms of enrichment are present, but water uses in these lakes are not impaired to the degree or frequency experienced in Clear Lake.

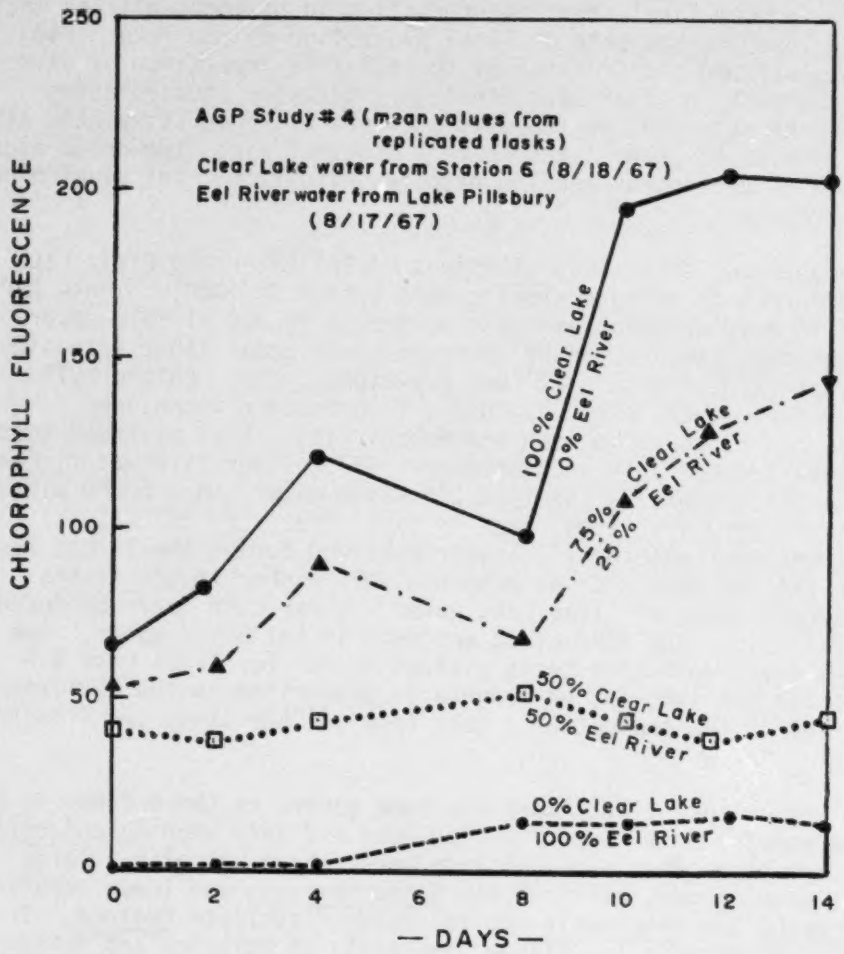
Some of the blue-green algae that flourish in Clear Lake (notably Anabaena) are known to fix atmospheric nitrogen, a fact that may account for their presence in the late summer when inorganic nitrogen levels are depleted by

prior algal activity. Phosphorus could limit blue-green algal growth in Clear Lake, if nitrogen fixation is intense.

Goldman has stated, however, that "Any diversion of lower nutrient water through the Clear Lake basin will reduce these (nitrogen and phosphorus) levels, but it is more likely that the reduction in nitrogen will be most significant in lowering the rate of algal production in the lake." [40]. This statement followed a discussion of the relative importance of nitrogen and phosphorus growth in Clear Lake, including bioassay studies using natural Clear Lake water and phytoplankton (where nitrogen stimulated algal growth) and examples of other lakes where nitrogen-fixing blue-green algae were found in high phosphorus and low nitrogen situations, yet algal blooms were not observed.

Laboratory incubations of various dilutions of Eel River and Clear Lake water were performed to measure algal growth potential (AGP). These AGP tests were of 14 days duration and were performed in 500 ml Erlenmeyer flasks at a constant temperature of 20° centigrade under light intensity of 500-1000 foot candles with a 12 hour day-night cycle. Chlorophyll was usually measured every other day using fluorescence techniques essentially as described by Yentsch and Menzel [41]. Five of these tests were carried out between July and September 1967. Clear Lake water, Eel River water, a mixture of 75% Lake and 25% River water and a 50-50 mixture of the two waters were incubated, each in duplicate. The AGP values recorded were the peak chlorophyll levels achieved during the 14 day test. In every case the AGP obtained was progressively higher in the flasks containing higher ratios of Clear Lake water. Clear Lake water produced from 2.5 to 21.7 times the AGP values achieved in Eel River water. The average of the five replicated tests yielded an AGP for Clear Lake 9.6 times that of the Eel samples, or roughly in proportion to the nutrient content observed in the two waters. Data from one AGP study are illustrated in Figure 10.

The algae in the culture flasks were the same genera as those found in the Lake when the samples were taken. During June and July when Aphanizomenon was the dominant blue-green algae in lake water there was also a large population of green algae, particularly Sphaerocystis, and lower populations of Oocystis and Schroderia and the green flagellate Euglena. The Eel River water produced a low diatom population of Melosira and Nitzchia in July. Later AGP tests in August yielded dominant populations of the blue-green algae Anabaena, Microcystis and lower numbers of Aphanizomenon in lake water incubations along with the diatoms Melosira and Fragilaria and the green alga Oocystis . Eel River water produced the diatoms Melosira and Nitzchia along with the coccoid green alga Ankistrodesmus and a filamentous green which was probably Mougeotia.



ENGLISH RIDGE PROJECT

ALGAL GROWTH POTENTIAL
CLEAR LAKE & EEL RIVER

U.S DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC SOUTHWEST REGION SAN FRANCISCO, CALIF.

FIGURE 10

It has previously been noted that the routing of Eel River water through Clear Lake would be expected to reduce water temperatures in the Lake. Any tendency toward lower summer water temperatures would in turn tend to retard algal growth rates.

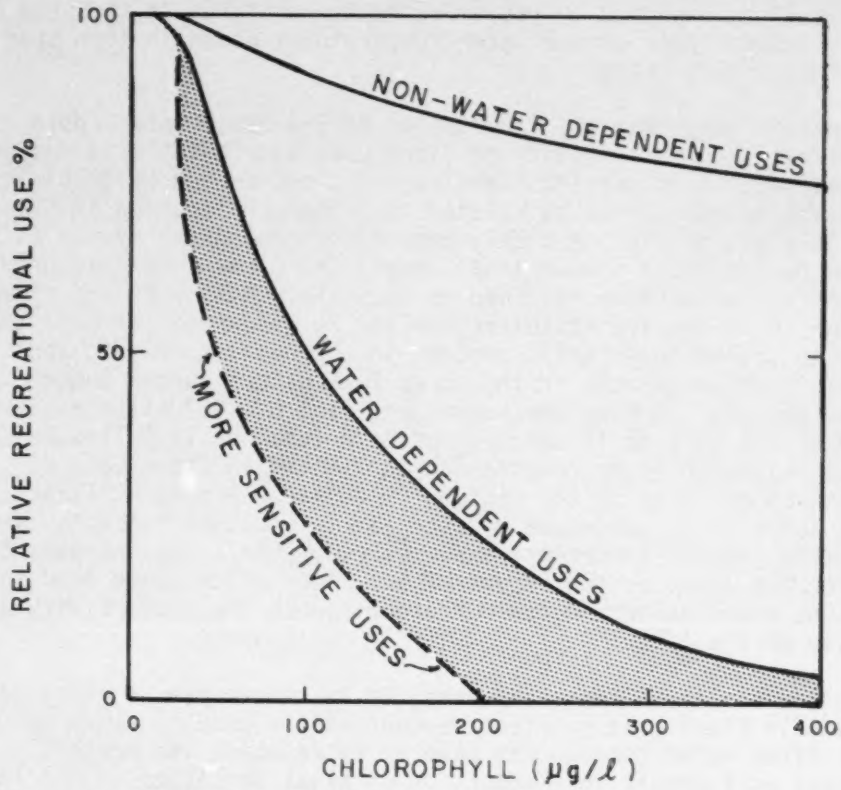
There is a possibility that the importation of Eel River water could cause an increase in the turbidity of Clear Lake attributable to suspended inorganic sediments. At present light restrictions caused by turbidity do not control the nuisance growths related to primary production in Clear Lake. The lake is, in fact, a highly productive biological system as demonstrated by the dense summer algal crops, the Clear Lake gnat problem and the high fish production recorded in the lake. Nutrients and algae within the water column are efficiently mixed by winds and currents that expose them to the photosynthetic process in the upper eutrophic zone. Low inorganic nitrogen levels in the upper lake waters during summer reflect this process. During the summer and fall of 1967 nitrate nitrogen was less than 0.18 mg/l in 14 samples out of a total of 18 collected by FWPCA. Thus, although light penetration is limited in Clear Lake as compared with other lakes in the region, extensive nutrient utilization is nonetheless achieved as evidenced by crop levels of algae, insects, and fish and by the limited laboratory analyses available. Any increase in turbidity brought about by the import of Eel River water would tend to diminish light penetration and could thereby reduce the productivity and algal density of the lake.

On the basis of the above considerations, it is reasonable to expect that any reduction in Clear Lake nutrient concentrations brought about by routing Eel River water through the Lake or by reducing its present nutrient input will result in a reduction of algal densities in the lake. The degree of improvement in the quality of lake waters will be in proportion to the reduction in nutrient concentrations achieved by these measures. This conclusion coincides with that reached in the recent Task Force Report on Upper Eel River Routing Studies [50] which considered water quality problems in Clear Lake.

Social Acceptance of Lake Water

As water quality varies, the range of social acceptance, expressed as recreational use, is great. The reaction of the public to water quality suggests a relationship between certain physical parameters, such as temperature, clarity, color, etc., and intensity of recreational use. Many of the physical conditions affecting the average recreationist are actually created by chemical and/or biological mechanisms. The turbidity, slimes and odors produced by algal populations are but one example.

A relationship was developed to relate relative recreation use to the extent of enrichment in Clear Lake. The curve shown in Figure 11 attempts to relate the range of water quality conditions found in lakes to public



NOTE!

1) Above curves compare water dependent recreational use (swimming, water skiing etc.) and non water dependent uses (camping, sight-seeing etc.) to levels of eutrophication in Clear Lake expressed here in terms of total chlorophyll.
These curves are meant to apply during the period May-October for any year. Water quality related benefits or detriments may be estimated from adjustments of projected recreational use using the curves.

2) Chlorophyll (a) concentrations refer to near surface algal crops. Ratios of chlorophyll to biologically available nutrients in the near surface region are assumed as 1:1 for phosphorus and 1:10 for nitrogen by weight.

ENGLISH RIDGE PROJECT

WATER QUALITY and RECREATIONAL USE

U.S DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC SOUTHWEST REGION SAN FRANCISCO, CALIF.

FIGURE 11

reaction to those conditions, assuming recreation alternatives exist. The relationship presented in Figure 11 represents the combined judgment of a number of persons having broad experience in eutrophic lake problems as well as the human reactions involved in recreation activities. It is included here as the best available basis upon which to estimate recreation use as affected by water quality changes anticipated in Clear Lake under alternative water quality control plans.

Data collected during 1967 field studies may be used to test the applicability of this relationship. During this survey recreationists and resort owners at Clear Lake were quite vocal concerning the algal nuisances and fish kills on the lake. Some effort was made to document the complaints through informal interviews by project personnel and through a recreation survey carried out during September 1967 by the Lake County Chamber of Commerce. This limited survey reached 122 recreationists and 25 resort owners around the lake. Water quality was acceptable for swimming to only 33 percent of those interviewed whereas it was acceptable to 84 percent of those participating in "sightseeing." The ranking in decreasing order of apparent sensitivity to water quality was swimming, water skiing, camping, fishing, boating and sightseeing. The study also showed that 46 percent of those interviewed, curtailed or eliminated participation in water dependent recreation use because of water quality considerations.

The applicability to Clear Lake of the relationship between recreational use and water quality shown in Figure 11 is roughly demonstrated by using the results of the survey where 46 percent avoided use of the lake while the total chlorophyll in Clear Lake water was approximately 100 µg/l. The population sampled was biased, however, in that those who did not go to the lake because of water quality considerations, were not sampled. This would indicate that the relationship shown in Figure 11 may be a conservative estimate of the aversion recreationists have to the quality of water in Clear Lake.

Future Recreational Use

Preliminary projections of demand for outdoor recreation in the Clear Lake area were made by the Bureau of Outdoor Recreation and are shown in Table 15. Angler days are not included in the projection. The Bureau of Outdoor Recreation is now making a more detailed study of the potential recreational use and the unit value of use of Clear Lake. When the results of their study become available, it may be necessary to adjust the recreational values used in this report.

Projected recreation demands are based upon projected population, increased per capita recreation rates, and the assumptions that development will keep pace with demand and that water quality does not significantly limit

TABLE 15

POTENTIAL RECREATIONAL USE

CLEAR LAKE BASIN

YEAR	:	RECREATION DAYS
1970		4,400,000
2020		13,200,000

the use. Use is expected to reach capacity by 2020 and be limited thereafter by highway access. However, at the present time, water quality conditions are such that algae blooms, fish kills, odor and other problems which occur periodically are aesthetically displeasing to most recreationists. These objectionable conditions result in a decrease in the number of recreation days that the public is willing to spend at Clear Lake.

The relationship between recreation use and the extent of nutrient enrichment of Clear Lake is considered to be reasonably well described by the relationship shown in Figure 11. This relationship and the projected nutrient levels in Table 12 were used to determine the reduction in potential recreational use of Clear Lake that would be expected as a result of various levels of wastewater treatment with or without the routing of Eel River water through Clear Lake. The results are shown in Table 16. The value of a recreation visitor-day used in these calculations was varied from 0.95 to 1.20 dollars to reflect the influence of water quality on the value of the recreational experience.

The data given in Table 16 show that by the year 2020, the recreational use projected ranges from 9.3 to 13.2 million visitor-days depending upon the level of water quality maintained in the Lake. The difference in annual value of the limits of this range of use would be 5.55 million dollars in 2020.

The lowest projected level of use would occur if no Eel River water were imported and present waste treatment practices were continued. By improving waste treatment and disposal practices or routing Eel River water through the Lake, or by doing both, the highest level of projected use may be approached. Accordingly, the value of the increase in projected use brought about by each incremental increase in Eel River import or improvement in wastewater treatment may be considered as a monetary benefit attributable to that action.

By this process it may be concluded that the annual routing of 190,000 acre-feet of Eel River water through Clear Lake will result in increased recreational use having a value of 21.2 million dollars when evaluated over a 100 year period at 4.625 percent interest. Additional developments in the Eel River Basin that would increase the diversion of water through Clear Lake would provide additional water quality improvement and thus increased recreational use of Clear Lake.

Improvements in present waste treatment and disposal practices would have a similar beneficial effect. Provision of tertiary waste treatment would yield benefits of 15.8 million dollars while diversion of all wastewaters for disposal outside of the Clear Lake Basin would yield benefits of 24.2 million dollars.

The maximum benefit may be achieved by combining the diversion of wastewaters with the import of 190,000 acre-feet of Eel River water. In this case the benefits to water quality improvement and the associated increase in recreational use are estimated to have a value of 34.9 million dollars.

TABLE 16

PROJECTED ANNUAL RECREATION USE AND VALUE

CLEAR LAKE BASIN

	1970		2020	
	Visitor Days	Annual Value	Visitor Days	Annual Value
Water Quality Not a Limiting Factor	4,400,000	5,280,000	13,200,000	15,840,000
Without Import of Eel River Water				
Present Level of Waste Treatment	3,398,000	3,908,000	9,354,000	10,289,000
Tertiary Treatment of Wastes	3,612,000	4,153,000	10,246,000	11,783,000
Export of Wastes	3,744,000	4,305,000	10,905,000	12,541,000
With Import of Eel River Water				
Present Level of Waste Treatment	3,790,000	4,359,000	10,520,000	12,098,000
Tertiary Treatment of Wastes	3,900,000	4,485,000	11,320,000	13,018,000
Export of Wastes	3,943,000	4,534,000	11,695,000	13,449,000

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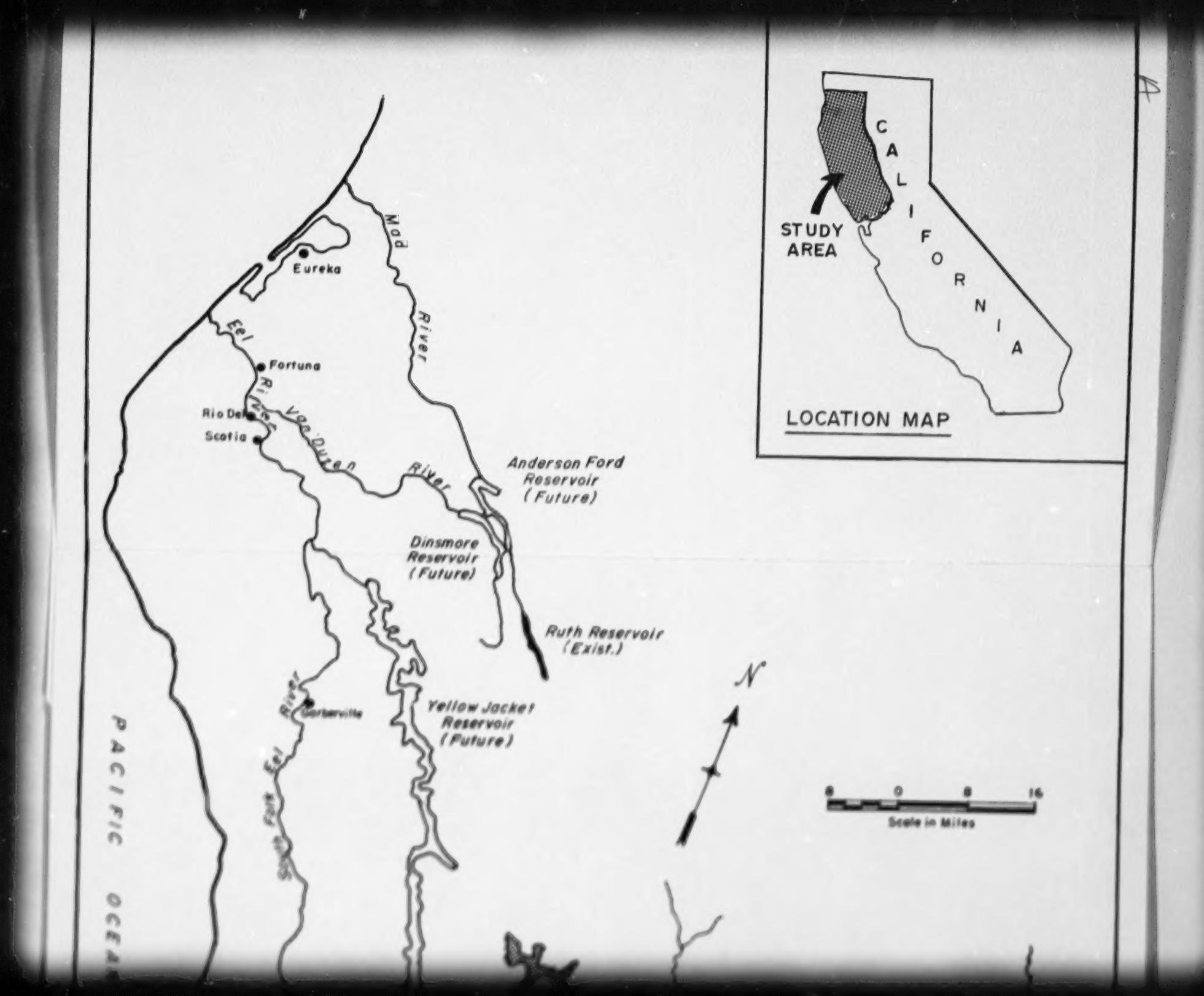
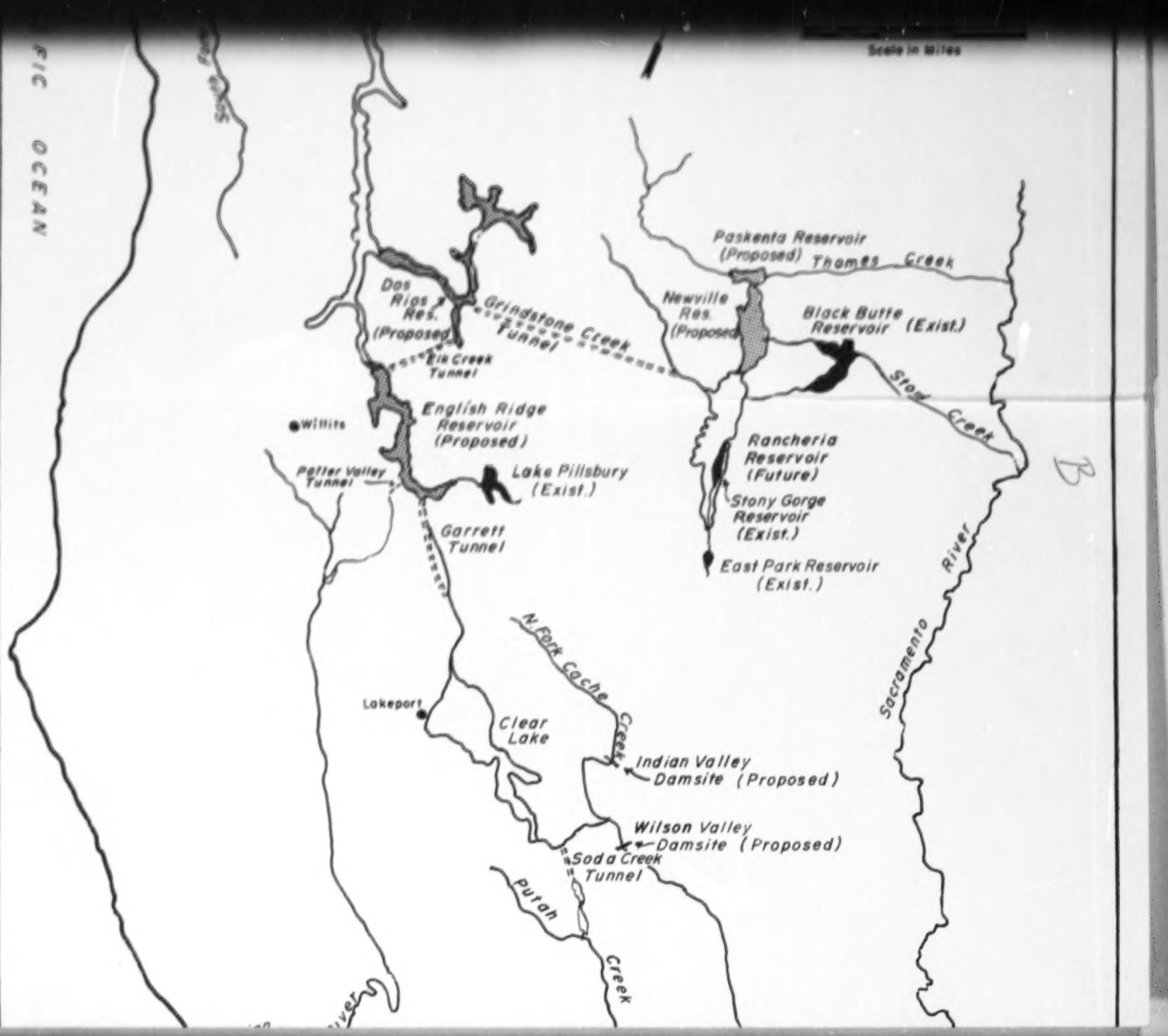

Eureka
Mad River
Eel River
Fortuna
Rio Dell
Scotia
Van Duzen River
Anderson Ford Reservoir (Future)
Dinsmore Reservoir (Future)
Ruth Reservoir (Exist.)
Yellow Jacket Reservoir (Future)
Garberville
South Fork Eel River
PACIFIC OCEAN
CALIFORNIA
STUDY AREA
LOCATION MAP
N
0
8
16
Scale in Miles


FIC OCEAN
Scale in Miles
Paskenta Reservoir (Proposed)
Thomes Creek
Dos Rios Res. (Proposed)
Grindstone Creek Tunnel
Newville Res. (Proposed)
Black Butte Reservoir (Exist.)
Elk Creek Tunnel
Stony Creek
Willits
English Ridge Reservoir (Proposed)
Rancheria Reservoir (Future)
Potter Valley Tunnel
Lake Pillsbury (Exist.)
Stony Gorge Reservoir (Exist.)
Garrett Tunnel
East Park Reservoir (Exist.)
Sacramento River
N Fork Cache Creek
Lakeport
Clear Lake
Indian Valley Damsite (Proposed)
Wilson Valley Damsite (Proposed)
Soda Creek Tunnel
Putah Creek
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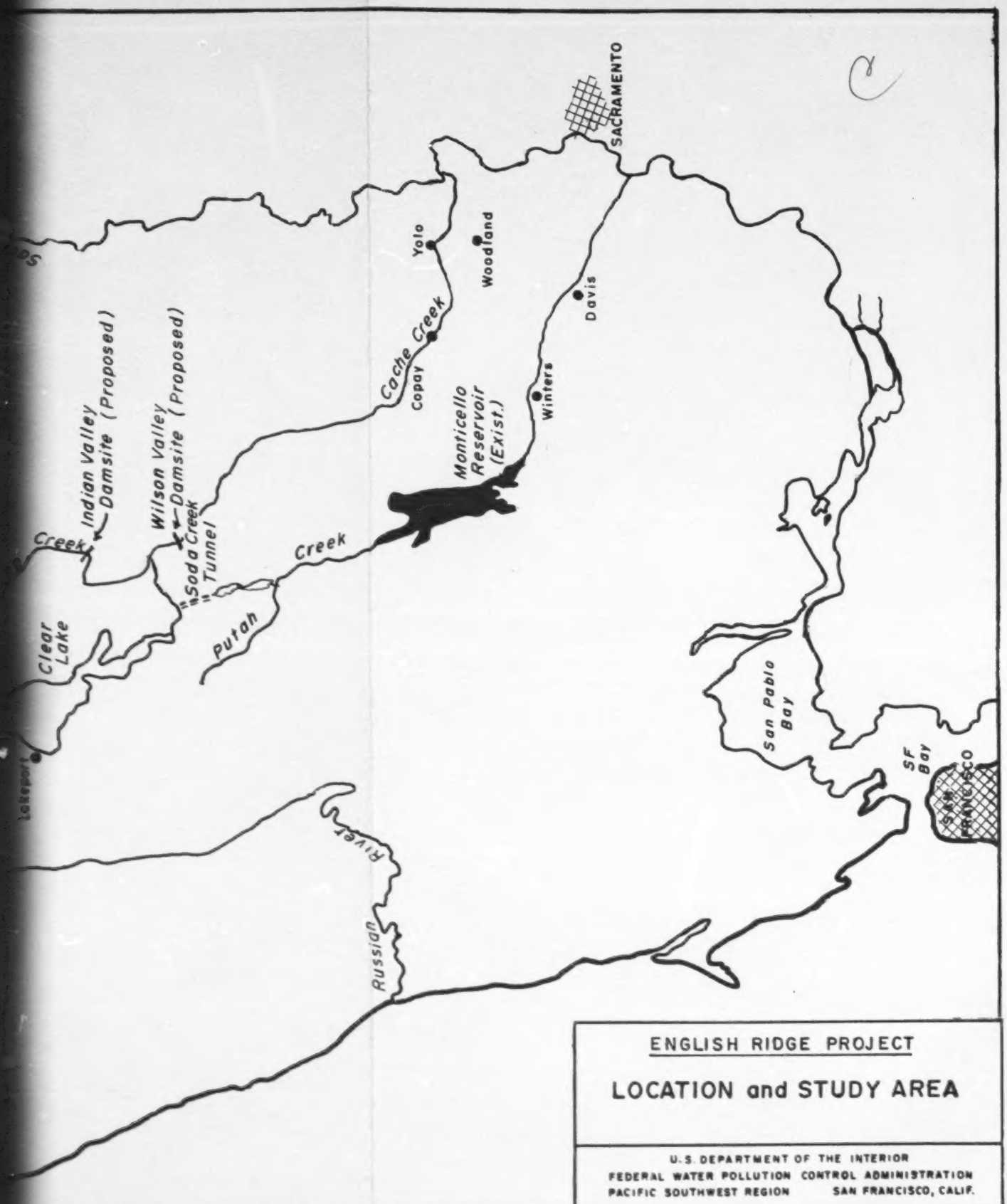

ENGLISH RIDGE PROJECT

LOCATION and STUDY AREA

U.S. DEPARTMENT OF THE INTERIOR
FEDERAL WATER POLLUTION CONTROL ADMINISTRATION
PACIFIC SOUTHWEST REGION SAN FRANCISCO, CALIF.

FIGURE 1